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ASSESSMENT OF CONSTRUCTION AGGREGATE SUITABILITY OF ROCKS UNDERLYING THE TORONTO AREA

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ABSTRACT

Three holes were drilled at Milton, Clarkson and Pickering by the Ontario Geological Survey. Core from these holes was used to assess the suitability of these rocks as construction aggregate. Samples were taken from between 52 and 620 m below the surface.

Core was crushed and submitted to the following tests: Magnesium Sulphate Soundness, Los Angeles Abrasion and Impact, Absorption and Relative Density, and Petrographic Examination. The rock cylinder expansion test and chemical analysis was used to test for the alkali-carbonate reaction. Total and water soluble chloride ion contents were determined on a number of samples.

The rocks of the Lindsay, Verulam, Bobcaygeon and Shadow Lake Formations are generally too shaley for high quality uses but are suitable for use as unbound granular base materials. The rocks of the Upper Gull River Formation are generally suitable for use as aggregate in concrete, asphalt and granular base. The rocks of the Lower Gull River Formation are probably unsuitable for use in concrete due to the alkali-carbonate reaction. High chloride ion contents may prevent the use of some rocks as aggregate in reinforced concrete due to the risk of chloride induced corrosion.

KEYWORDS: Aggregate, Testing, Alkali-carbonate rock reaction, concrete, chloride, Deep Mining, chemical analysis, expansion, clay.

INTRODUCTION

As part of the Ontario Geological Survey's deep drill hole program, three boreholes were drilled at Milton, Clarkson and Pickering. Preliminary descriptions of the drill holes can be found in Johnson (1983). Borehole locations are shown on Figure 1. In order to make a preliminary assessment of aggregate suitability at these locations, selected samples from the various geological formations were tested by the Engineering Materials Office of the Ministry of Transportation and Communications. Durability testing and physical property determinations, as well as testing for alkali-carbonate reactivity was undertaken as part of this program.

This study was conducted as part of a larger program on the feasibility of deep mining of aggregates, details of which will be found in a report by Grass (1986).

SAMPLE COLLECTION & PREPARATION

1. Bulk Samples

Samples for routine aggregate durability testing and physical property determination were taken from the drill core by splitting. The split core was taken to the MTC Downsview laboratory, crushed pass 19.0 mm and sieved into size fractions in preparation for testing.

2. Alkali-Reactivity Samples

Samples for alkali-reactivity testing were taken from 6cm long split sections of core. Following the preparation of 9 x 30 mm cores for reactivity testing (described below), a representative sample was taken for chemical analysis from the remainder of the core. This was crushed pass 2 mm in a small laboratory jaw crusher and pulverized pass 150 um using a shatter box.

LABORATORY TESTING

Bulk Samples

Following sample preparation, representative subsamples of the crushed aggregate were tested for determination of:

Absorption and relative density (MTC LS-604).

Resistance to abrasion and impact in the Los Angeles test (MTC LS-603).

Soundness by use of magnesium sulphate (MTC LS-606).

Petrographic examination and determination of Petrographic Number (MTC LS-609).

Total and water soluble chloride ion (MTC LS-411).

The methods used are described in the MTC laboratory testing manual. The sample locations and test results are shown in Tables 1, 2, and 3.

Alkali-Reactivity Samples

Each section of core was subjected to the test for potential alkali reactivity of carbonate rocks for concrete aggregate, the rock cylinder expansion test (ASTM C586-69,1981). Briefly a 9 x 30 mm core was taken from each sample. The end was finished plane and smooth using a miniature lathe. The length was recorded in a device with a dial gauge reading to 0.0001 inch. The core was stored in water for 4 days and the length measured again. The core was then immersed in 1M NaOH in a closed 30 ml container. Length was measured at intervals of 7, 14, 21, 28, 42, 112, 196 days and 1 year. In a number of cases it was not possible to obtain samples that would not fracture during handling and preparation. In these cases cores were taken parallel to the bedding. In two cases, samples were so weak that no core could be obtained.

Sub-samples representative of each sample were submitted for chemical analysis by X-ray fluorescence spectrometry. This was done by the Geoscience Laboratories of the Ontario Geological Survey. Samples were also tested by MTC for determination of insoluble residue. This was done on 10 g of pass 150 um powder by digestion in hot hydrochloric acid.

The results are shown in Tables 4 to 9, and shown graphically in Figures 3 to 9.

MTC Quality Requirements

For reference and comparison, the Ministry of Transportation and Communications quality requirements for coarse aggregates are presented in Appendix 1.

DISCUSSION

1. Durability testing and physical property determinations.

Tables 1, 2, and 3 show the results of durability testing and physical property determinations on samples from the Milton, Pickering and Clarkson boreholes respectively. In general, the results show a relationship between shale and/or clay content and durability. The percentage of shaley carbonate and shale are given in Tables 1, 2 and 3 to demonstrate this relationship.

The results of tests on samples of the Lindsay Formation show that in general this rock is not suitable for use in concrete and asphalt. Average hot mix/concrete and granular petrographic numbers (PNs) for this formation are 174 and 138 respectively. The average magnesium sulphate loss is 23%. The exception to this is the upper 25m of the Lindsay Formation in the Milton borehole which meets the specifications (See Appendix 1) for hot mix/concrete and granular i.e. average PNs of

119 and 108 respectively, and a magnesium sulphate loss of 8%. The upper 25 m of the Lindsay Formation in the Milton borehole is suitable for use in asphalt. Durability test results indicate that this formation is generally suitable for granular use.

The Verulam Formation has a high shale and shaley carbonate content, which is reflected in the results of the durability tests. Hot mix/concrete petrographic numbers in excess of 200 and magnesium sulphate losses in excess of 26% were obtained for this rock. The material is generally unsuitable for all uses. Specific levels will probably be suitable for use as granular. Limited durability test results on the Verulam Formation from the Clarkson Borehole, for example, shows this material is suitable for use as granular base.

Similarly, the Bobcaygeon Formation in the Pickering and Milton boreholes has a high shale and shaley carbonate content (see Tables 1 and 2). Hot mix/concrete petrographic numbers greater than 300 and magnesium sulphate losses in excess of 35% were obtained on rock from this formation. The material in the Pickering and Milton boreholes is unsuitable for all uses. Specific levels may be suitable for use as granular base. Testing was performed on only one sample from the Bobcaygeon Formation in the Clarkson borehole. These results indicate this material is suitable for all uses.

Durability testing indicates that the Gull River Formation is in general suitable for all aggregate uses. Average hot mix/concrete and granular PNs for this formation are 110 and 104 respectively. The average magnesium sulphate loss is 6%.

The Shadow Lake Formation was not tested as part of this program. This formation is probably unsuitable for use in concrete and asphalt due to the high shale content. Specific levels are possibly suitable for granular. Testing will be required.

Precambrian granitic gneiss was not tested as part of this program. From a physical durability viewpoint, this rock is probably suitable for all aggregate uses. It is a potential source of HL1 aggregate. Carbonate rocks are not used as HL1 aggregate (for high traffic volumes) because of the ease with which they are polished by traffic.

2. Alkali-reactivity testing

There are two alkali-aggregate reactions that have been found in rocks of Trenton-Black River age in Southern Ontario. These are:

a) Alkali-carbonate reaction.

Argillaceous dolomitic limestones which are apparently sound in conventional testing cause expansion and cracking of portland cement concrete. Expansion of concrete in the field has been measured as high as 1.2% in three years (Rogers, 1985). The type section for these reactive rocks is the lower Gull River Formation at the Pittsburg quarry near Kingston (Figure 12) where the

reaction was first described by Swenson (1957) and Swenson and Gillott (1960). Alkali-carbonate reactive rocks have not been found in the Bobcaygeon, Verulam or Lindsay Formations.

b) Alkali-silica reaction.

Recent work in the Ottawa and Montreal areas has shown that rocks of the Bobcaygeon Formation may be alkali-silica reactive. Cryptocrystalline silica may be present in these rocks as chert and chalcedony. This silica is soluble in alkaline cement paste solutions. Alkali-silica gel is formed in voids in the concrete. The formation and expansion of this gel under moist conditions causes expansion and cracking within ten years. At present only some rocks of the Bobcaygeon Formation have been found to be deleteriously reactive. Other rocks of Trenton-Black River age may contain chert and chalcedony usually as selective silicification of fossil fragments or as discrete chert nodules.

In this present study, testing has been devoted toward identifying the more common alkali-carbonate reactive rocks. The possibility of alkali reactive silica being present has not been investigated. There are three tests considered useful for recognizing alkali-carbonate reactive rocks:

a) Rock cylinder expansion test (ASTM C586).
b) A chemical test (See Rogers, 1986).
c) Concrete prism expansion test (CSA A23.2-14A, 1977).

Because of limited sample availability, only the first two tests have been conducted in this study. For final acceptance of any aggregate, the concrete prism expansion test should be considered conclusive.

The results of expansion testing are shown in Tables 7, 8 and 9 and shown graphically in Figures 6, 7 and 8. The results of chemical testing are shown in Figure 11.

The chemical test has been developed from a study of rocks of the Bobcaygeon and Gull River Formations (Rogers, 1986). Figure 13 shows the graph that has been developed based on that study. Potentially alkali-expansive rocks fall in a distinct field. In Figure 11 the same boundaries as shown in Figure 13 have been superimposed on the data obtained in the study of the drill core. There are four samples which are considered to be alkali-carbonate expansive (49, 54, 87 and 112). Other expansive samples plotting in the alkali-expansive field are thought to have expanded due to some other mechanism, probably related to the properties of, or amount of clay in the rock.

In Figures 6, 7 and 8 it can be seen that many samples from the Lindsay Formation expanded considerably when stored in NaOH solution. These rocks, with the exception of sample 54, did not have the expansion characteristics of alkali-carbonate reactive rock. Alkali-carbonate reactive rock generally gives small expansions on wetting in water (<0.1%). Subsequent expansion in alkali solutions then becomes significant. In the case of samples from the Lindsay Formation, considerable expansion was noted after 4 days storage in water (Figures 3 and 4). Subsequent expansion in sodium hydroxide was, however, considerably greater.

Figure 10 shows percent expansion in sodium hydroxide against expansion on wetting in water. It can be seen that there is a relationship between expansion on wetting and subsequent expansion in alkali. There are some exceptions; rocks that showed little expansion on wetting, but significant expansion in alkali. These rocks are tentatively identified as potentially alkali-carbonate expansive. In Figure 14, the expansion in alkali has been plotted against alumina content for the rocks of the Lindsay Formation. Alumina content is considered to be a good measure of clay content in sedimentary carbonate rocks (Baxter and Harvey, 1969; Rogers, 1986). Clays are the only minerals present in feldspar-free carbonates, that contribute alumina to an analysis. It should be noted, however, that Dolar-Mantuani (1975) reported that feldspar did occur as a minor constituent of the insoluble residues in many samples from the Lindsay Formation. In Figure 14, it can be seen that expansion is often related to alumina content. There are some notable exceptions, where rocks with a high alumina content did not show significant expansion. These may be rocks with either a non-expansive type of clay present or a significant detrital or authigenic feldspar content.

Work by Dolar-Mantuani and Laakso (1974) on the swelling properties of rocks from the Verulam Formation showed the presence of an expansive, mixed layer illite/montmorillonite clay. In view of the juxtaposition of the Lindsay/Verulam Formations, the apparently continuous sedimentation history and similar diagenetic history, it is probable that a mixed layer clay is also present in rocks of the Lindsay Formation. This is confirmed by the statement in Dolar-Mantuani (1975, p.37) that an "interstatified expanding clay mineral within illite" was found in the acid insoluble residues of the Lindsay Formation. The presence of this expansive clay may account for the remarkable expansions shown by some of the Lindsay rocks in sodium hydroxide solution.

Sodium montmorillonite is the most expansive of all clays (Gillott, 1968, p.109). Sodium ions from the sodium hydroxide may have occupied exchange sites in the montmorillonite part of the mixed layer clay. The hydration and swelling accompanying this process may be sufficient to account for the observed expansions.

The rocks from the Lindsay Formation are not considered alkali-carbonate expansive, which is characterized by a de-dolomitisation reaction accompanied by water adsorption on previously dry clay surfaces (Gillott, 1975). They are, however, apparently unstable in alkaline solutions. Whether or not this instability has a deleterious effect in portland cement concrete is unknown.

There is a significant correlation ($r=0.82$, $n=72$) between alumina content and magnesium sulphate soundness of sedimentary carbonate rocks (Rogers, 1977). There is also a significant correlation ($r=0.86$, $n=19$) between freeze/thaw loss and alumina in carbonate rocks (Hudec, 1980). In both examples, as alumina becomes greater the durability is reduced. Generally, when alumina exceeds about 2%, carbonate rocks are usually unsuitable for use in portland cement concrete and asphalt. As can be seen in Tables 4 and 5 and Figure 14, the alumina content of the Lindsay Formation often exceeds 2%. The generally high clay (alumina) content and instability in alkaline solutions revealed by this testing suggest that rock of the

Lindsay Formation is not a good candidate for use as a source of portland cement concrete aggregate. Beneficiation may be possible but will probably be economically unattractive.

There were insufficient samples from the Bobcaygeon Formation to come to definite conclusions about alkali-carbonate expansivity. The five samples tested were non-expansive. This correlates with the known non alkali-carbonate reactive nature of rocks of the Bobcaygeon Formation.

The rocks of the Gull River Formation gave results that enable the alkali-carbonate reactive zone to be identified with some accuracy. In Figure 12, the expansion characteristics of samples from a section through the lower Gull River Formation at Kingston are shown. The rocks at the top of the section (samples 69-76) show contraction on storage in sodium hydroxide. They are not alkali-carbonate reactive. Rocks below sample 69 show varying amounts of expansion and contraction. The significantly expansive samples (generally greater than 0.1% @ 4 weeks or 0.2% @ 16 weeks) are considered to be alkali-carbonate reactive. Whether or not a processed aggregate will be classed as acceptable or unacceptable depends on the average expansion of samples within the extraction zone. Preliminary unpublished data, indicates that an average rock cylinder expansion exceeding about 0.08% (at 4 weeks) for the extractive unit indicates unacceptable performance. Thus the lst lift of the Pittsburg quarry (Figure 12) gave an average expansion of rock cylinders at 4 weeks of 0.38% and gave an unacceptable expansion of 0.15% at 1 year when tested in the concrete prism expansion test (maximum of 0.025% at 1 year) and also had very poor field performance.

In Figures 6, 7 and 8, the top of the probable alkali-carbonate reactive zone is shown. The rocks of the Gull River Formation above this boundary may be considered to be non alkali-carbonate reactive. The rocks below the boundary contain alkali-carbonate reactive rocks together with non reactive rocks. The available information is inadequate to state that all the rocks of the alkali-carbonate reactive zones are unacceptable for use in concrete. It is probable that parts of this zone may be acceptable if adequately blended with non-reactive rocks. More detailed sampling (at 0.3 m intervals) and testing should allow the reliable prediction of the likely suitability for use in portland cement concrete.

3. Chloride Content

The corrosion of reinforcing steel in concrete is a major cause of the deterioration of concrete bridge decks and parking garages in Ontario. One of the controlling factors of corrosion is the amount of chloride in the concrete. Corrosion will not normally take place in prestressed concrete if the water soluble chloride content is below about 0.1% by weight of Portland cement (Stark, 1984).

Assuming no other contribution of water soluble chloride from the mix water, additives etc. a coarse aggregate containing about 0.03% water soluble chloride will give the concrete sufficient chloride to exceed 0.1% chloride by weight of cement. There are no specifications in Ontario for maximum water soluble chloride ion content of aggregates. In Europe, specifications have been introduced for coarse aggregate (See Rogers and Woda, 1977):

Greater London Council		0.03% NaCl
Netherlands	Reinforced concrete	0.05% Cl^-
	Prestressed concrete	0.005% Cl^-
West Germany	Prestressed concrete	0.02% Cl^-
Austria		0.01% Cl^-

The Ontario Hydro specifications at Darlington called for a maximum water soluble chloride ion content of 0.025% in the total concrete as mixed.

Testing of rocks of the Gull River Formation in a 30 m deep quarry near Cornwall, Ontario showed an average total chloride ion content of 0.014% and a water soluble chloride ion content of 0.006%.

Smith (1978) in a study of rock near Bath, found the following chloride ion contents:

VERULAM	
West quarry	0.004% water soluble Cl-
East quarry	0.019% water soluble Cl-
BOBCAYGEON	0.006-0.068% total Cl-
GULL RIVER	0.007-0.034% total Cl-

Samples of core from the three boreholes were tested for total and water soluble chloride ion content. Results are presented in Table 10. Eight (8) samples of the Lindsay Formation, two (2) samples of the Verulam Formation, one (1) sample of the Bobcaygeon Formation and eleven (11) of the Gull River Formation were tested. Results vary considerably with geological formation and borehole. However, average values for the four geological formations are comparable. Average water soluble chloride ion contents range from 0.0433 to 0.0575 percent. These high values should be regarded with concern.

Prior to using these aggregates in reinforced concrete it would be necessary to demonstrate consistent and low soluble chloride ion content. Alternatively the innocuous nature of the chloride on corrosion of reinforcing steel should be demonstrated. If the chloride is effectively immobilized due to pore size effects, the rock may not contribute toward corrosion. The occurrence of high soluble chloride ion contents from deep formations may be an effective constraint on their use as Portland cement concrete aggregates.

CONCLUSIONS

1. Durability Testing

The high shale content makes the Lindsay Formation unsuitable for use in concrete without beneficiation. Generally this formation is unsuitable for use in asphalt, although specific levels particularly in the upper part of the formation do meet the specifications. The material is suitable for granular base uses.

In general, the Verulam Formation is unsuitable for all aggregate uses. Specific levels are probably suitable for granular base use.

Durability testing indicates that the Bobcaygeon Formation in the Pickering and Milton Boreholes is unsuitable for all uses. Test results from a single sample from the Clarkson borehole indicate the material is suitable for all uses. Further testing on core from this borehole would be necessary to substantiate this.

The Gull River Formation is suitable for most aggregate uses.

The Shadow Lake Formation and the underlying Precambrian granite gneiss were not tested as part of this program. The Shadow Lake Formation is however probably unsuitable for concrete and asphalt uses. The Precambrian granite gneiss is probably suitable for all aggregate uses and in particular is a potential candidate for use as a source of HL 1 aggregate (for use in high volume roads where good skid resistance and durability is required.)

2. Alkali-reactivity Testing

The Lindsay Formation is not alkali-carbonate reactive. Alkali-reactivity testing has shown that these rocks expand in alkali solution, which, it is postulated, may be due to the presence of an expansive, mixed layer clay. The generally high clay content and expansive properties of these rocks make them unsuitable for use as Portland cement concrete aggregates.

The Bobcaygeon Formation is not alkali-carbonate reactive but past field performance in the Ottawa and Montreal areas has shown that certain zones may be alkali-silica reactive. Further testing would be necessary to demonstrate the suitability of this formation for use in Portland cement concrete.

The Gull River Formation can be divided into two zones: the upper part of the formation which is not alkali-carbonate expansive and the lower part where a mixture of expansive and non-expansive rocks are found. In the Pickering drill hole there is a thickness of 10.8 m in the upper, non-expansive zone (199.1-209.9 m). The lower zone is 17.3 m thick (209.9-227.2m). Observation of the Gull River Formation in the outcrop area has shown chert nodules in the upper part of the formation (near Kingston and Marmora) and chert in the lower part (near Orillia). Further testing would be necessary to demonstrate the non alkali-silica reactive nature of this rock.

3. Chloride Content

The occurrence of high contents of soluble chloride ions in the rocks of Trenton-Black River age from these deep boreholes may be an effective constraint on their use as Portland cement concrete aggregate in reinforced and prestressed concrete.

4. Summary

Conclusions are summarized in Figure 2.

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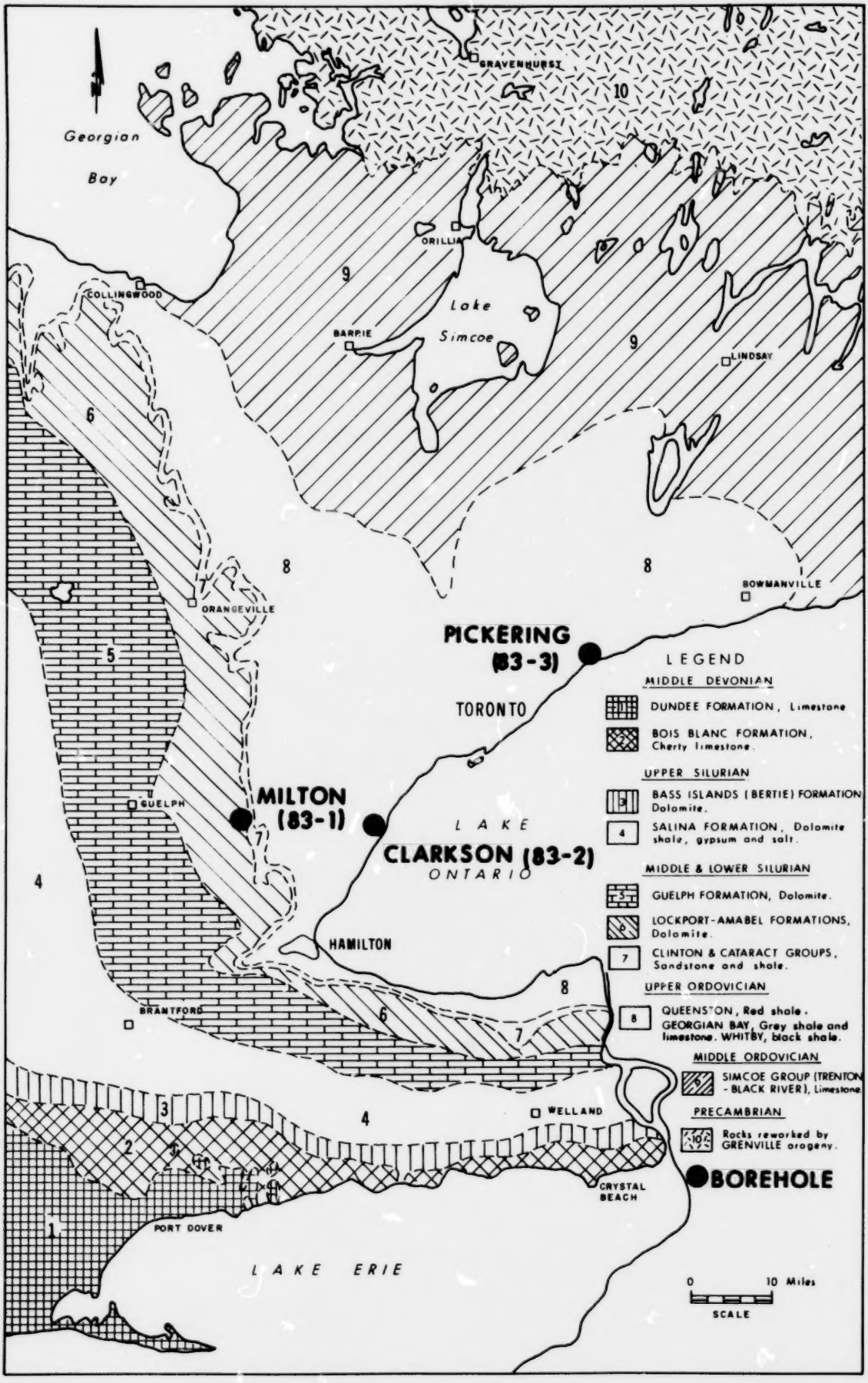
FIGURE 1. Location of Boreholes



FORMATION	AVERAGE THICKNESS (m)	POTENTIAL AGGREGATE USE			REMARKS
		CONCR.	ASPHALT	GRAN.	
Lindsay	48	NO	POSS	YES	High shale content makes formation unsuitable for concrete without beneficiation. Specific levels probably suitable for asphalt e.g. Milton borehole.
Verulam	58	NO	NO	POSS	High shale content generally makes formation unsuitable for all uses. Specific levels possibly suitable for granular e.g. Clarkson borehole.
Bobcaygeon	34	NO	NO	POSS	Possible alkali-silica reaction in concrete. High shale content generally makes formation unsuitable for all uses. Specific levels possibly suitable for granular eg. Clarkson borehole.
Gull 1	10	YES	YES	YES	Should be tested for Alkali-silica reaction in concrete, not alkali-carbonate reactive.
River 2	18	NO	YES	YES	Alkali-carbonate reactive in concrete; beneficiation may be possible. Alkali reactive zones may not be suitable for use in asphalt due to high freeze-thaw loss.
Shadow Lake	8	NO	NO	POSS	Probably unsuitable in concrete and asphalt due to high shale content. Specific levels possibly suitable for granular. Testing required.
Precambrian	-	POSS	YES	YES	Probably suitable for asphalt and granular. Possible alkali-silica reaction in concrete. Testing required.

CONCR. = Portland Cement Concrete
GRAN. = Granular Aggregates
POSS. = Possibly Suitable

FIGURE 2: SUMMARY OF AGGREGATE SUITABILITY IN DEEP BOREHOLES

FIGURE 3: Expansion of kock Cylinders on Immersion in Water for 4 days (ASTM C586)

FIGURE 4: Expansion of Rock Cylinders on Immersion in Water for 4 days (ASTM C586)

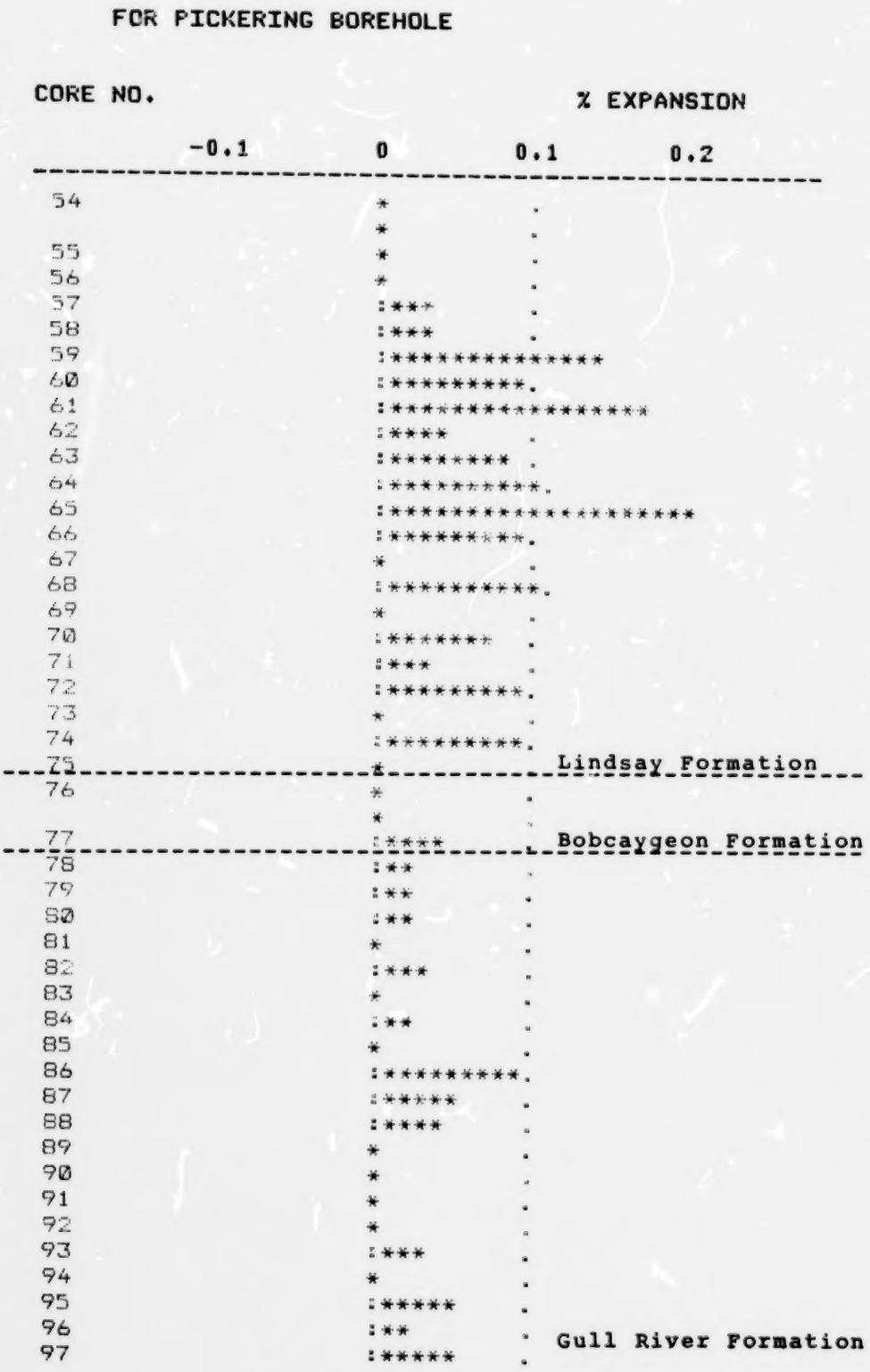


FIGURE 5: Expansion of Rock Cylinders on Immersion in Water for 4 days (ASTM C586)

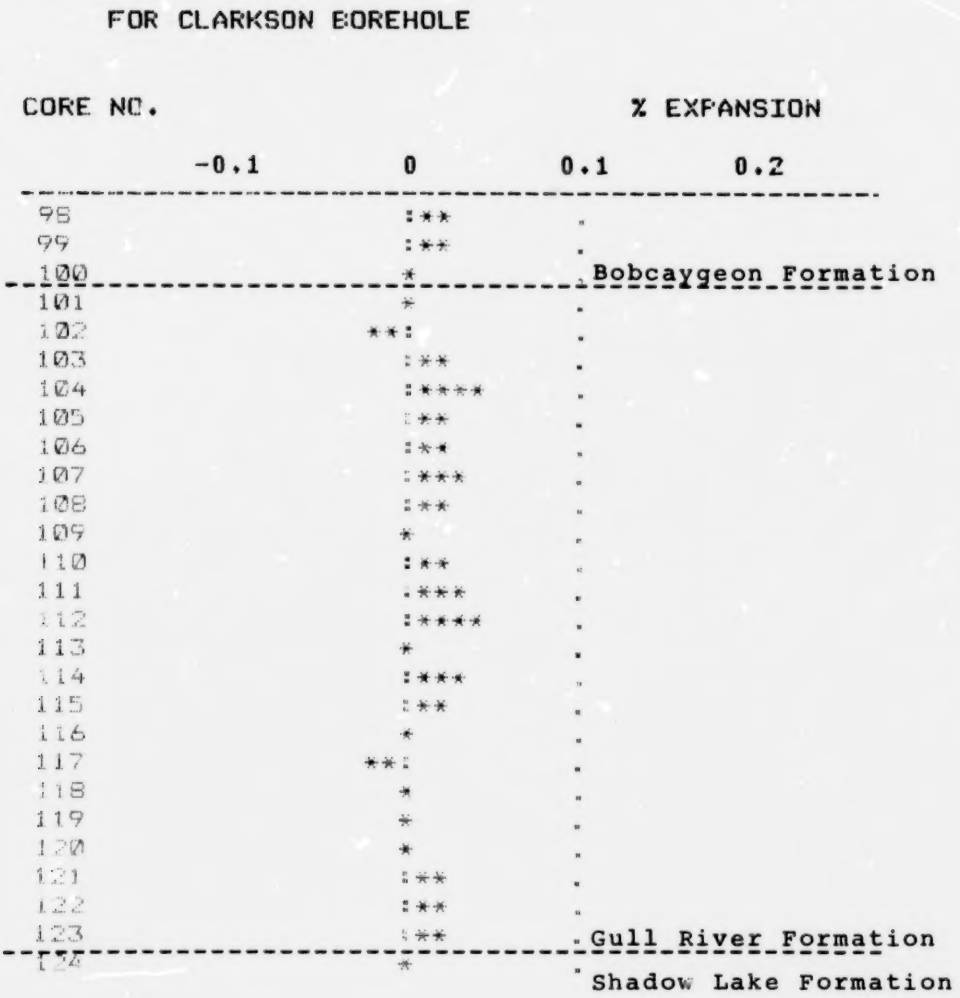


FIGURE 6: ALKALI REACTIVITY TEST FOR ROCK CORES **(ASTM C586)**

FOR MILTON
28 WEEKS READINGS

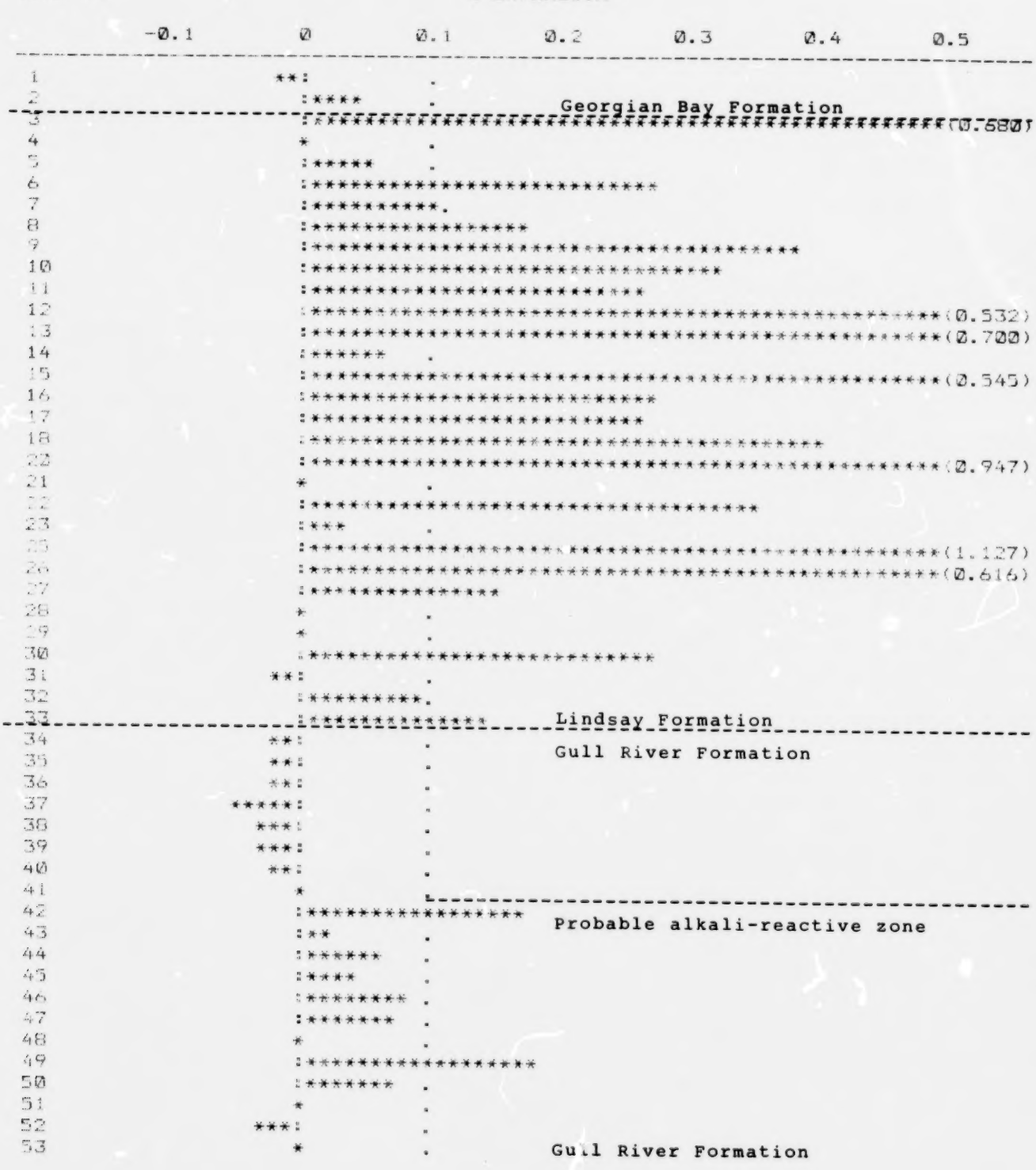


FIGURE 7: ALKALI REACTIVITY TEST FOR ROCK CORES **(ASTM C586)**

FOR PICKERING BOREHOLE
28 WEEKS READINGS

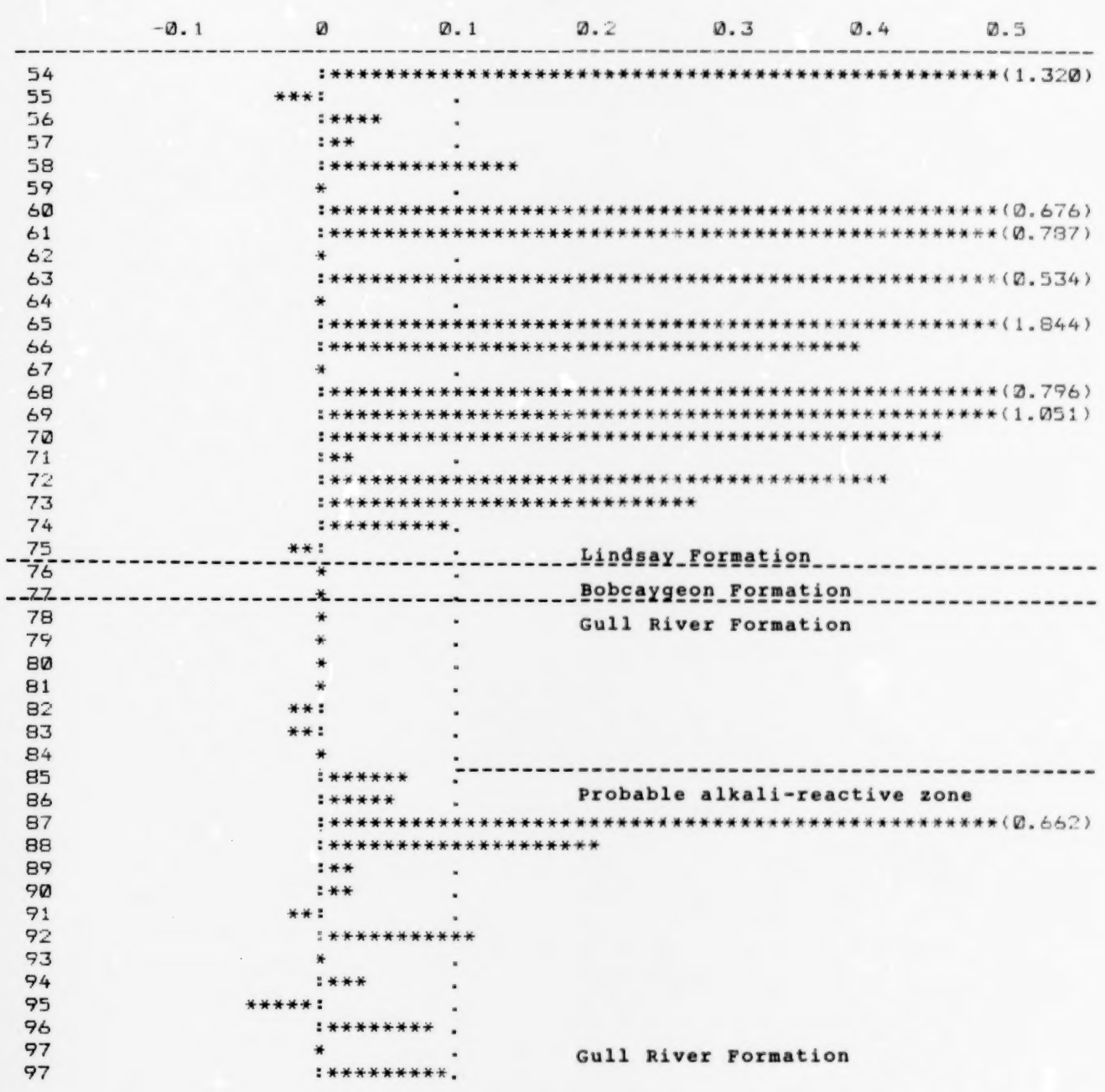
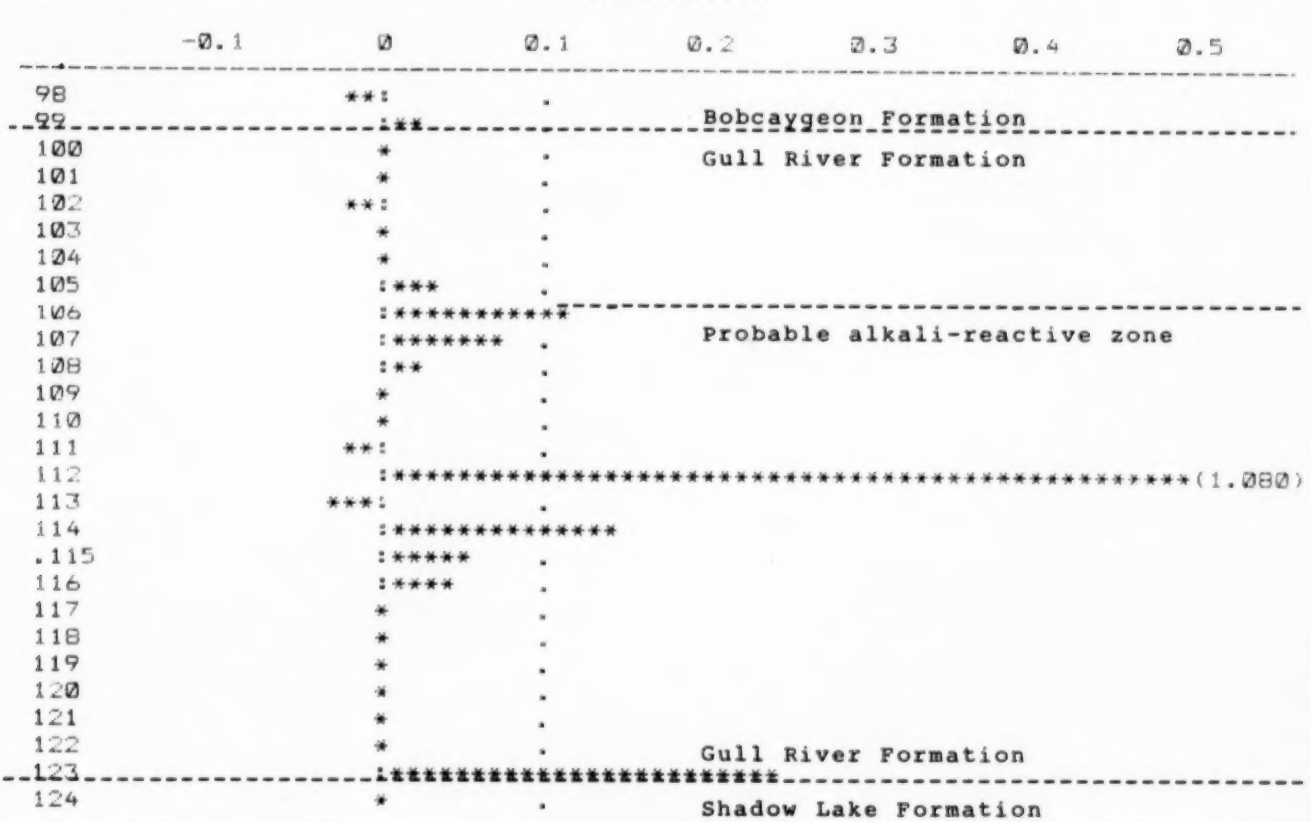


FIGURE 8: ALKALI REACTIVITY TEST FOR ROCK CORES **(ASTM C586)**

FOR CLARKSON BOREHOLE
28 WEEKS READINGS



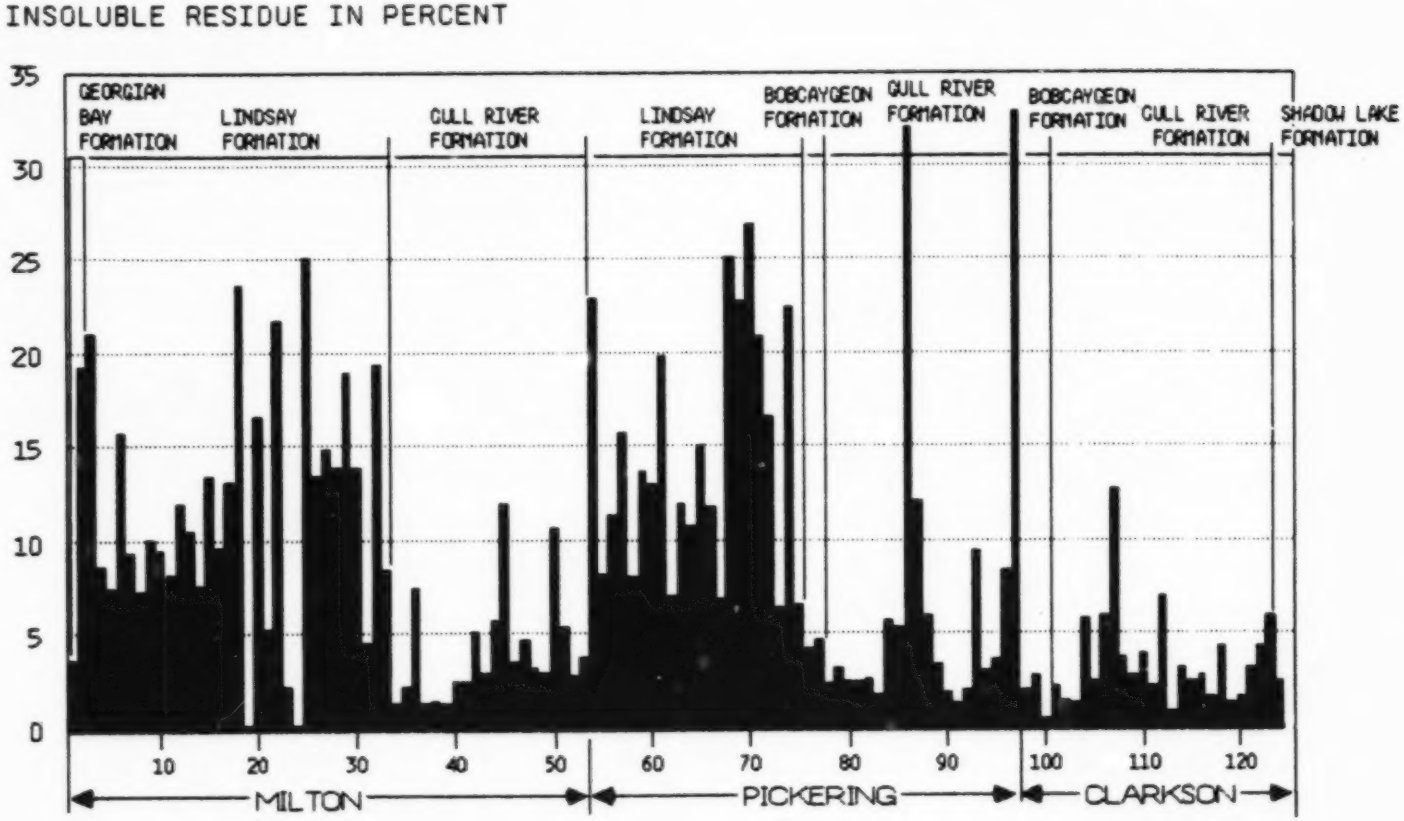


FIGURE 9: Insoluble Residue Results

● SAMPLES JUDGED TO BE ALKALI-CARBONATE REACTIVE - BASED ON EXPANSION CHARACTERISTICS AND CHEMISTRY

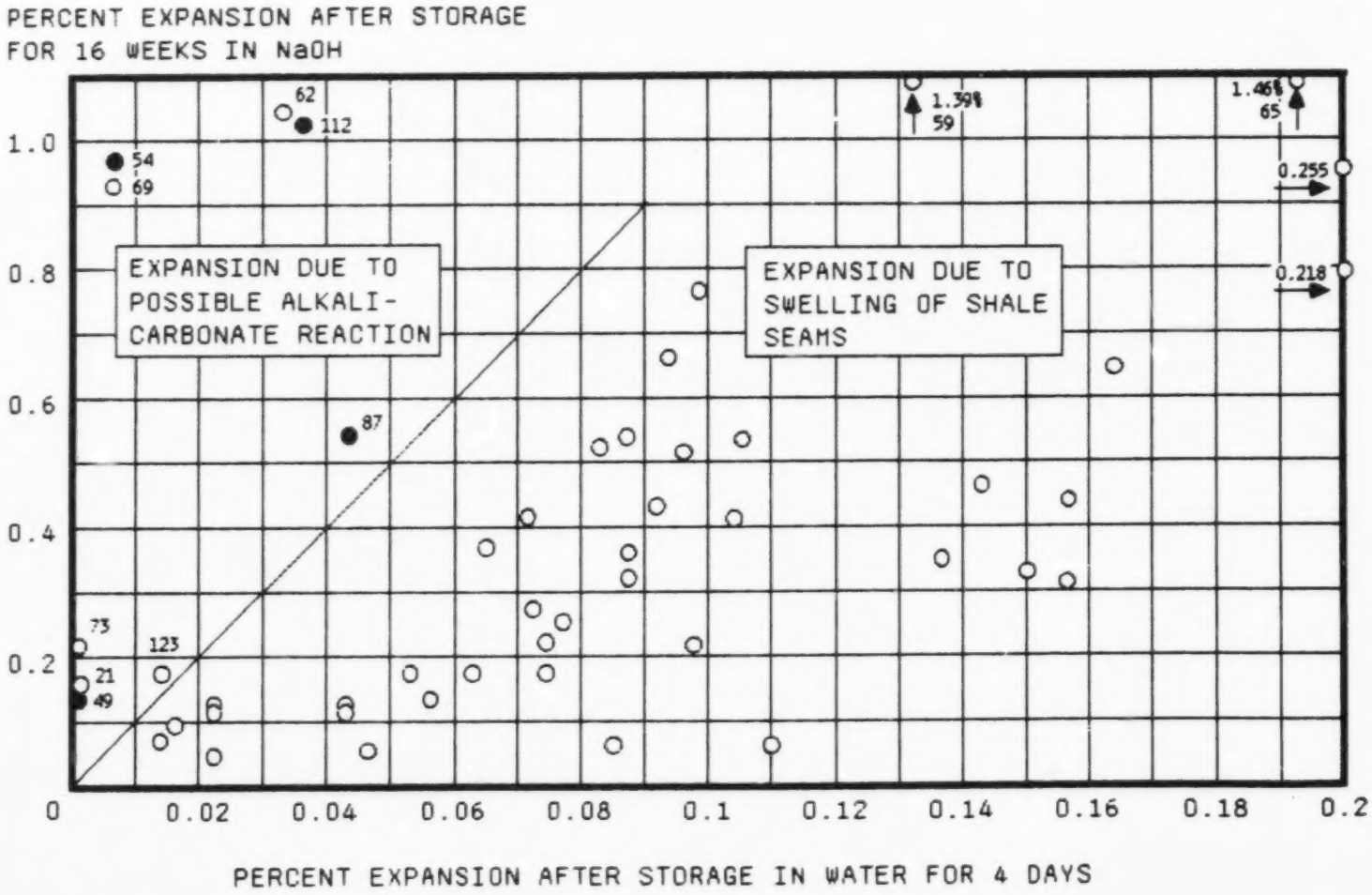


FIGURE 10: Percent Expansion in 1 M NaOH against Expansion on Wetting

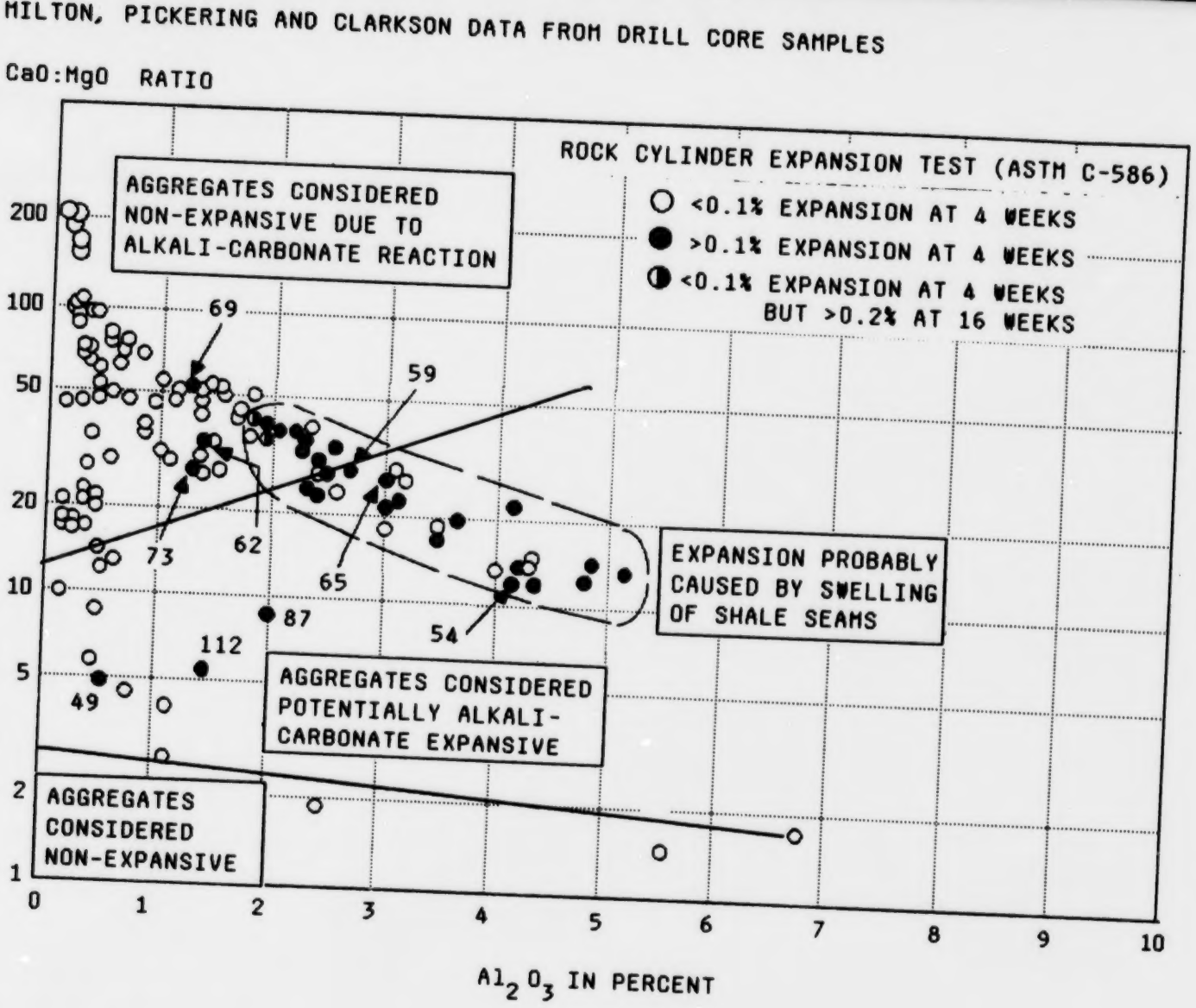


FIGURE 11: CaO:MgO Ratio against Al_2O_3 for Samples from Milton, Pickering and Clarkson Boreholes

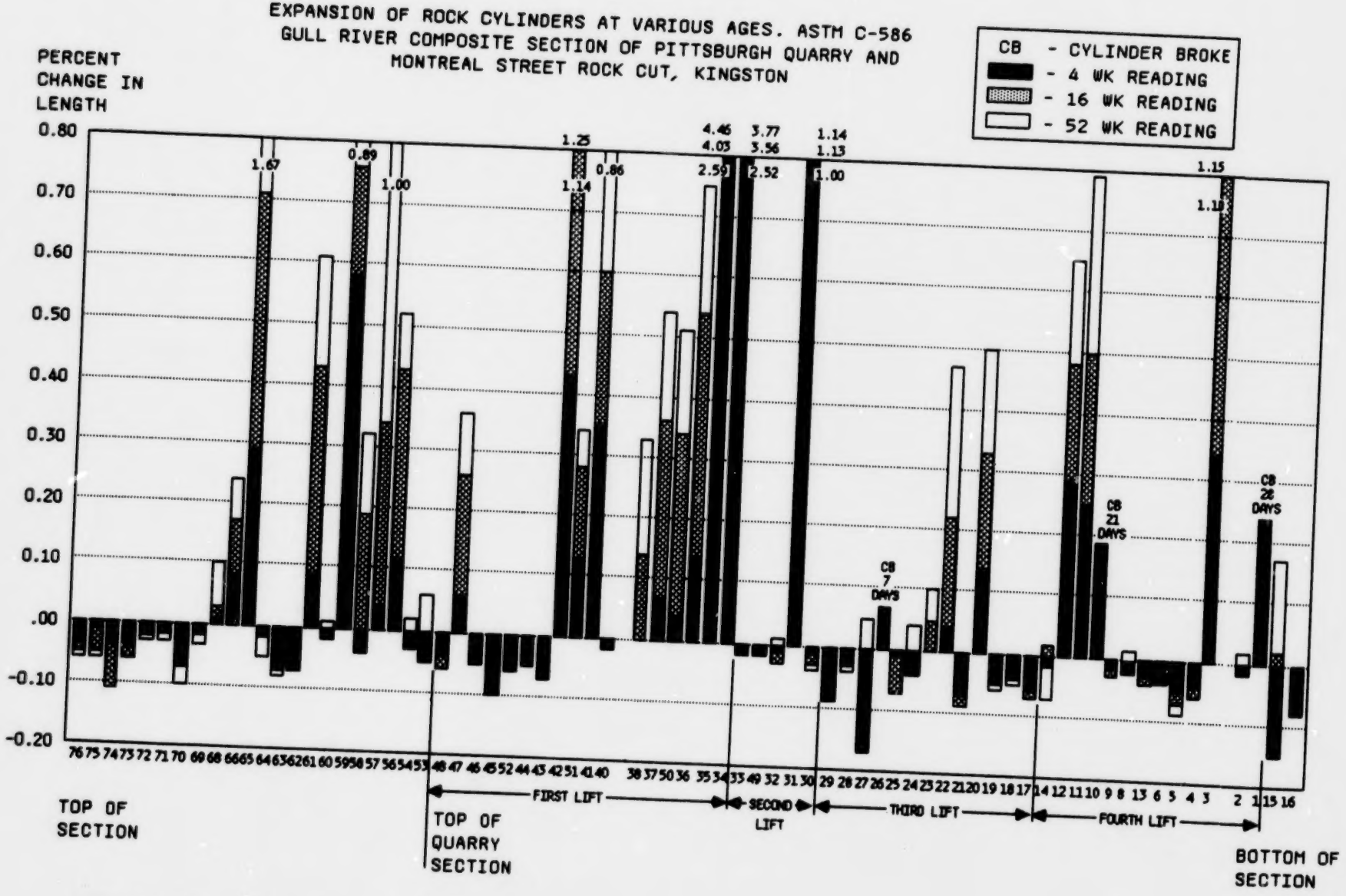


FIGURE 12: Expansion of Rock Cylinders in 1 M NaOH (ASTM C586) for a Suite of Samples from the Lower Gull River Formation

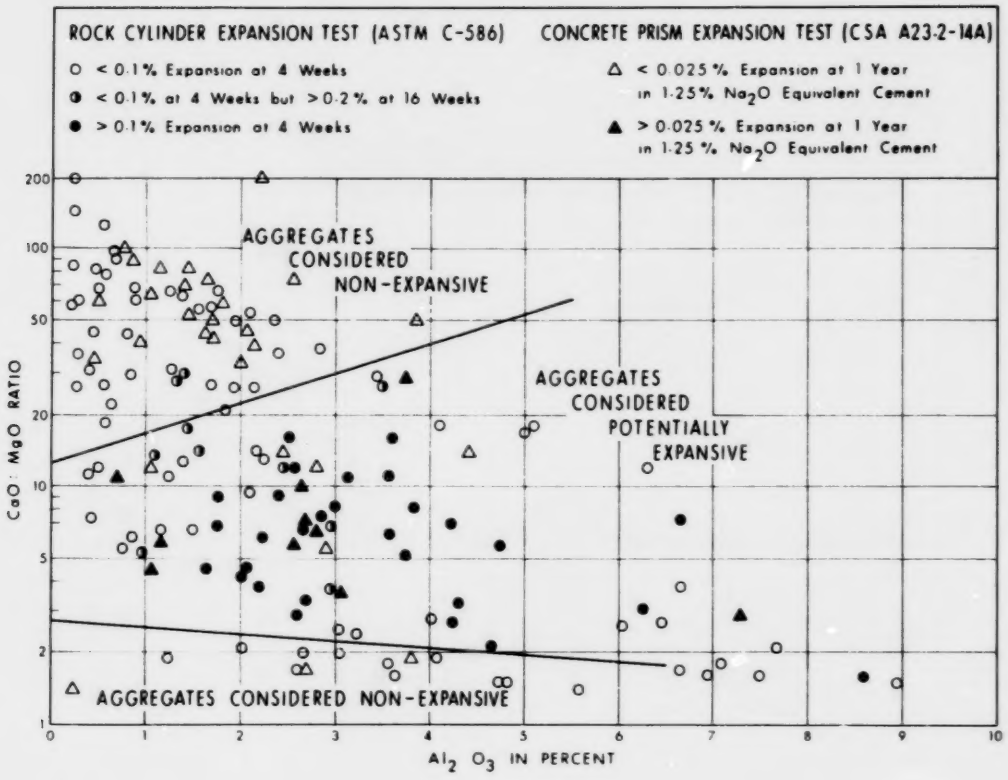


FIGURE 13: CaO:MgO Ratio against Al_2O_3 for a Suite of Alkali-Reactive and Non-Reactive Samples from the Gull River and Bobcaygeon Formations (from Rogers, 1986)

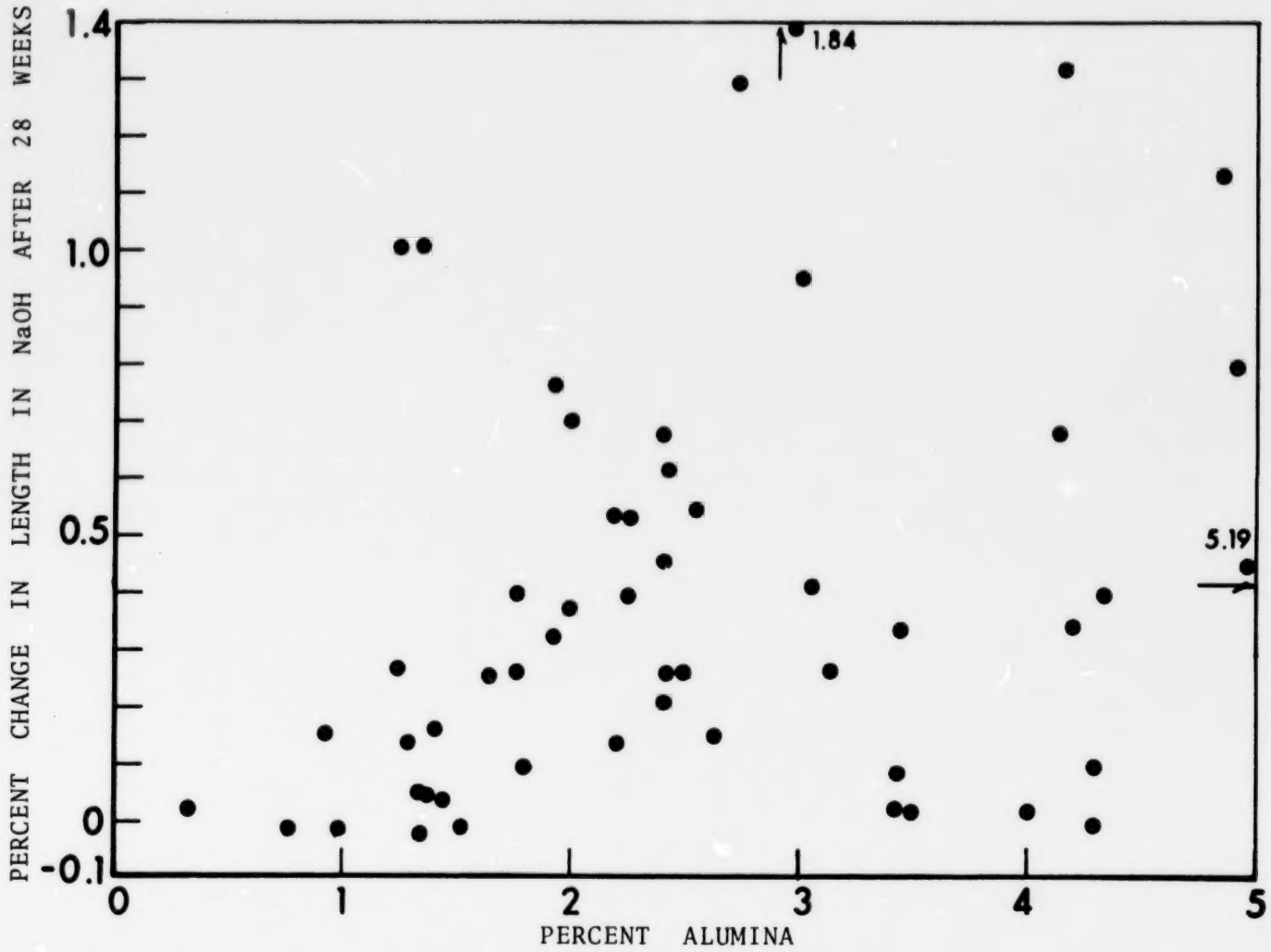


FIGURE 14 Percent change in length after storage of rock cylinders in NaOH for 28 weeks against percent alumina for samples from the Lindsay Formation, Milton and Pickering boreholes.

DEPTH (m)	GEOLOGICAL FORMATION	M.T.C. #	% SHALEY CARBONATE/SHALE			PN		$MgSO_4$	L.A.	ABSN.	BULK REL. DENSITY	CHLORIDE ION %	
			SL.SHY.	SHY.	SH.	HL./CONC.	GRAN.	%	%	%		TOTAL	WATER SOL.
444.51 - 448.77	Lindsay	84-B-40019	6.1	1.1	1.0	127	115	10	--	0.67	2.674		
449.39 - 457.68	Lindsay	84-B-40020	3.6	0	0	110	101	5	23	0.69	2.669		
455.86 - 461.42	Lindsay	83-B-40106	5.0	0.4	0	114	102	7	20	0.70	2.673	0.0045	0.018
461.65 - 469.51	Lindsay	84-B-40021	10.6	5.0	0	147	125	28	22	0.94	2.662	0.0413	0.0389
469.51 - 475.32	Lindsay	84-B-40022	24.9	9.9	0	213	159	23	22	0.94	2.657	0.0244	0.0214
475.32 - 482.23	Lindsay	84-B-40023	13.2	9.0	0	187	151	33	23	0.97	2.658	0.0448	0.0426
527.15 - 532.65	Verulam	83-B-40101	8.0	8.8	14.0	333	316	35	29	1.32	2.660	0.0472	0.0460
549.89 - 562.64	Bobcaygeon	85-B-45103	18.0	6.7	0.7	181	146	20	25	0.67	2.674		
562.64 - 575.32	Bobcaygeon	85-B-45102	24.6	17.8	8.6	316	268	39	24	1.08	2.648		
575.32 - 587.59	Bobcaygeon	85-B-45101	18.7	14.6	4.7	287	249	37	24	1.22	2.646		
596.13 - 601.20	Gull River	84-B-40007	14.0	23.0	0	114	111	3	26	0.23	2.702	0.0244 0.0248	0.0196 0.0211
601.50 - 605.10	Gull River	84-B-40008	11.0	10.0	0	107	105	5	--	0.47	2.697	0.0524 0.0569	0.0449 0.0514
605.14 - 606.22	Gull River	84-B-40009	23.0	1.0	0.1	153	107	62*	--	2.01	2.655	0.1668	0.1668
607.58 - 612.86	Gull River	83-B-40104	2.2	0	0	105	100	5	22	0.57	2.702	0.0541	0.0462
612.86 - 619.23	Gull River	84-B-40010	3.0	0.8	0	109	104	5	22	0.60	2.701	0.0567	0.0484

* Insufficient material for stone $MgSO_4$, therefore, conducted on retained 4.75 mm.
SL. SHY. = slightly shaley; SHY. = shaley; SH = shale; $MgSO_4$ = Magnesium Sulphate Soundness Loss; L.A. = Los Angeles Abrasion and Impact Loss;
ABSN. = Absorption
NOTE: M.T.C. Quality Requirements for Coarse Aggregates are given in Appendix 1.

TABLE 1: Results of Aggregate Durability Testing and Physical Property Determinations; Milton Borehole

PICKERING BOREHOLE

DEPTH (m)	GEOLOGICAL FORMATION	M.T.C. #	% SHALEY CARBONATE/SHALE			PN		$MgSO_4$ %	L.A. %	ABSN. %	BULK REL. DENSITY	CHLORIDE ION %	
			SL.SHY	SHY.	SH.	HL./CONC.	GRAN.					TOTAL	WATER SOL.
51.94 - 56.39 62.63 - 67.03	Lindsay	84-B-40024	12.7	3.6	2.6	181	145	18	20	1.14	2.640 –	0.0678	0.0630
56.39 - 62.63	Lindsay	83-B-40099	5.4	1.8	0	120	109	9	21	0.87	2.663	0.0637	0.0603
67.07 - 73.64	Lindsay	84-B-40025	21.8	10.5	0	196	152	25	22	1.14	2.643	0.0694	0.0644
73.64 - 79.04	Lindsay	84-B-400.6	27.5	7.2	0	207	148	47	28	1.31	2.639	0.0658	0.0633
102.11 - 108.09	Verulam	83-B-40100	11.7	13.6	11.2	337	315	38	24	1.67	2.661	0.0701	0.0690
147.83 - 161.54	Bobcaygeon	85-B-45100	25.8	14.4	4.7	288	244	35	27	1.15	2.651		
161.54 - 175.76	Bobcaygeon	85-B-45099	25.3	17.4	6.2	298	251	36	24	1.01	2.656		
175.26 - 182.80	Bobcaygeon	85-B-45098	11.2	21.2	15.2	402	380	46	24	1.55	2.619		
182.87 - 188.90	Bobcaygeon	83-B-40105	6.6	2.4	4.7	168	155	19	24	0.91	2.663	0.0434	0.0433
196.89 - 204.11	Gull River	84-B-40011	0.2	0	0	101	100	3	25	0.37	2.688	0.0346	0.0301
204.42 - 210.35	Gull River	83-B-40102	5.6	2.4	0.6	127	116	9	28	0.54	2.684	0.0110	0.0064
212.02 - 217.01	Gull River	84-B-40012	1.4	0.2	0	104	101	8	21	0.74	2.704		
217.01 - 221.85	Gull River	84-B-40013	0.5	0	0	101	100	2	--	0.40	2.722	0.0374	0.0291
221.85 - 225.55	Gull River	84-B-40014	1.4	0	0	105	100	9	19	0.78	2.716		

SL. SHY. = slightly shaley; SHY. = shaley; SH. = shale; $MgSO_4$ = Magnesium Sulphate Soundness Loss; L.A. = Los Angeles Abrasion and Impact Loss; ABSN. = Absorption
NOTE: M.T.C. Quality Requirements for Coarse Aggregates are given in Appendix 1.

TABLE 2: Results of Aggregate Durability Testing and Physical Property Determinations; Pickering Borehole

CLARKSON BOREHOLE

DEPTH (m)	GEOLOGICAL FORMATION	M.T.C. #	% SHALEY CARBONATE/SHALE			PN		$MgSO_4$ %	L.A. %	ABSN. %	BULK REL. DENS.	CHLORIDE ION %	
			SL. SHY.	SHY.	SH.	H.L./CONC.	GRAN.					TOTAL	WATER SOL.
329.18 - 331.95	Lindsay	83-B-40109	22.0	6.4	2.0	194	150	14	20	--	--		
388.62 - 391.70	Verulam	83-B-40110	19.2	10.1	1.4	202	163	26	22	0.89	2.666		
434.34 - 438.91	Bobcaygeon	83-B-40111	3.7	0	0	107	100	4	25	0.30	2.687		
438.99 - 444.98	Gull River	84-B-40015	2.0	0.8	0	110	106	4	28	0.40	2.680	0.0457	0.0420
446.69 - 452.63	Gull River	84-B-40016	3.6	0	0	112	102	13	22	0.74	2.697	0.0852	0.0766
454.26 - 468 00	Gull River	84-B-40017	1.3	1.5	0	110	100	2	24	0.50	2.699	0.0813	0.0706
466.34 - 469.18	Gull River	83-B-40108	3.2	0	0.2	110	104	2	20	0.30	2.732		
468.15 - 474.30	Gull River	83-B-40018	3.0	0.4	0	108	102	2	23	0.34	2.707		

Note: M.T.C. Quality Requirements for Coarse Aggregate are given in Appendix 1.

* Insufficient material for stone $MgSO_4$, therefore, conducted on retained 4.75 mm.
SL. SHY. = slightly shaley; SHY. = shaley; SH. = shale; $MgSO_4$ = Magnesium Sulphate Soundness Loss; L.A. = Los Angeles Abrasion and Impact Loss; ABSN. = Absorption

TABLE 3: Results of Physical Property Determination and Aggregate Durability Testing; Clarkson Borehole

MILTON BOREHOLE														
M.T.C. SAMPLE NO.	M.N.R. SAMPLE NO. (meters)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	CaO: MgO	L.O.I.	TOTAL
1	218.39	2.63	0.61	0.24	0.81	52.9	0.17	0.21	0.02	0.00	0.04	65	41.8	99.4
1D		2.64	0.62	0.24	0.84	53.0	0.22	0.21	0.02	0.01	0.04	63	41.6	99.4
2	219.37	14.1	3.00	0.79	2.12	37.6	0.14	1.01	0.11	0.00	0.04	18	35.1	94.0
3	442.30	17.3	4.12	0.91	1.66	36.0	0.16	1.01	0.17	0.04	0.04	22	35.2	96.6
4	445.95	6.81	1.52	0.56	0.92	49.2	0.16	0.43	0.06	0.04	0.04	53	40.2	99.9
5	446.85	6.05	1.37	0.57	1.15	49.7	0.15	0.41	0.05	0.05	0.04	43	40.2	99.7
6	448.20	13.4	3.12	0.88	1.58	39.9	0.14	0.76	0.13	0.11	0.05	25	36.9	97.0
7	449.20	8.01	1.79	0.52	0.99	47.1	0.17	0.49	0.07	0.04	0.04	48	39.4	98.6
8	450.18	5.57	1.41	0.42	0.90	50.2	0.18	0.41	0.06	0.05	0.03	56	40.5	99.7
9	451.08	8.43	2.00	0.64	1.26	45.9	0.18	0.54	0.07	0.05	0.04	36	39.4	98.5
10	452.04	8.00	1.93	0.55	1.35	46.4	0.17	0.52	0.07	0.07	0.04	34	39.6	98.7
11	452.77	6.48	1.63	0.49	1.06	48.6	0.11	0.46	0.06	0.04	0.04	46	40.3	99.3
12	454.66	9.98	2.26	0.63	1.32	44.1	0.16	0.61	0.09	0.06	0.04	33	39.3	98.6
13	455.80	8.82	1.99	0.62	1.27	45.5	0.14	0.56	0.08	0.06	0.04	36	39.4	98.5
14	461.52	6.24	1.35	0.49	1.04	49.8	0.14	0.40	0.05	0.04	0.04	48	40.4	100.0
15	462.53	11.4	2.55	0.61	1.35	42.8	0.15	0.73	0.09	0.03	0.03	32	37.7	97.4
16	464.40	8.04	1.76	0.52	1.12	47.1	0.15	0.52	0.06	0.05	0.03	42	39.7	99.1
17	465.55	11.3	2.41	0.67	1.66	42.9	0.13	0.70	0.08	0.03	0.03	26	38.0	97.9
18	466.54	21.3	4.34	1.04	2.54	32.7	0.16	1.13	0.17	0.05	0.04	13	33.5	97.0
20	468.20	14.1	2.98	0.80	1.88	39.4	0.18	0.82	0.11	0.04	0.03	21	36.3	96.6
20D		14.0	3.01	0.80	1.79	39.4	0.20	0.82	0.10	0.04	0.03	22	36.8	97.0
21	469.10	4.26	0.93	0.40	1.08	51.3	0.15	0.30	0.03	0.03	0.03	47	41.5	100.0
22	470.20	19.9	4.20	0.96	2.20	34.2	0.16	1.09	0.16	0.04	0.03	15	34.4	97.3
23	471.22	1.82	0.32	0.24	1.88	52.7	0.13	0.11	0.01	0.01	0.04	28	43.0	100.2
25	473.31	23.0	4.86	1.13	2.63	31.4	0.15	1.23	0.18	0.03	0.03	12	32.9	97.5
26	474.22	11.6	2.42	0.75	1.90	41.7	0.11	0.72	0.08	0.06	0.03	22	38.0	97.4
27	475.60	12.7	2.61	0.71	1.80	41.5	0.14	0.73	0.09	0.05	0.03	23	37.1	97.5
28	476.77	11.6	2.41	0.69	1.85	41.8	0.05	0.72	0.09	0.04	0.03	23	39.5	98.8
29	477.73	16.5	3.45	0.92	2.12	37.0	0.07	0.96	0.12	0.06	0.03	17	34.9	96.1
30	479.68	12.1	2.49	0.72	1.57	41.4	0.07	0.76	0.09	0.04	0.03	26	37.6	96.9
31	480.66	3.48	0.76	0.39	1.02	52.3	0.12	0.26	0.02	0.02	0.03	51	41.5	99.9
32	481.21	17.1	3.43	0.87	1.91	36.9	0.06	0.97	0.12	0.03	0.03	19	34.8	96.2

NOTE: D = Duplicate Analysis

Where SiO_2 and Al_2O_3 values are over range, the 'total' column is less than 100%

TABLE 4: Chemical Analysis by XRF for Milton Borehole

MILTON BOREHOLE														
M.T.C. SAMPLE NO.	M.N.R. SAMPLE NO. (meters)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	CaO: MgO	L.O.I.	TOTAL
33	482.08	7.11	1.30	0.64	1.48	48.0	0.11	0.41	0.04	0.08	0.03	32	39.8	99.0
34	596.13	0.77	0.12	0.13	0.23	55.2	0.15	0.03	0.00	0.00	0.02	240	43.1	99.8
35	597.75	1.41	0.29	0.19	0.49	54.4	0.13	0.10	0.00	0.00	0.02	111	42.6	99.6
36	597.34	6.08	1.61	0.49	1.13	49.9	0.16	0.51	0.05	0.01	0.02	44	39.9	99.9
37	598.42	0.67	0.09	0.11	0.11	55.3	0.16	0.03	0.00	0.01	0.02	503	43.0	99.5
38	599.15	0.87	0.17	0.13	0.26	55.0	0.12	0.05	0.00	0.01	0.02	211	43.3	99.9
39	600.06	0.76	0.13	0.17	0.32	55.0	0.16	0.04	0.00	0.01	0.02	172	42.8	99.4
40	601.27	2.40	0.43	0.21	0.76	52.9	0.13	0.14	0.01	0.01	0.02	70	42.1	99.1
41	602.24	1.40	0.45	0.17	0.95	53.2	0.12	0.18	0.01	0.01	0.02	56	42.7	99.2
42	602.81	3.52	1.01	0.28	0.96	52.1	0.14	0.40	0.03	0.01	0.02	54	41.3	99.8
43	603.74	1.79	0.40	0.17	0.77	53.7	0.14	0.17	0.01	0.01	0.02	70	42.5	99.7
44	604.82	3.99	0.75	0.56	9.12	41.9	0.02	0.29	0.03	0.00	0.08	4.6	43.1	99.8
45	606.08	12.4	2.45	0.90	14.9	28.4	0.00	0.63	0.08	0.02	0.05	1.9	41.2	101.0
45D		12.9	2.58	0.90	14.7	28.3	0.04	0.64	0.08	0.02	0.06	1.9	40.7	100.9
46	606.61	2.45	0.47	0.27	4.05	50.0	0.10	0.18	0.01	0.01	0.04	12	42.9	100.4
47	607.38	3.54	0.80	0.22	1.29	52.1	0.11	0.32	0.02	0.01	0.02	40	41.6	100.0
48	610.13	1.35	0.29	0.21	2.49	51.9	0.11	0.11	0.01	0.01	0.03	21	43.4	99.9
49	613.96	2.26	0.51	0.44	8.85	42.6	0.01	0.16	0.01	0.02	0.07	4.8	44.0	98.9
50	615.28	8.35	1.80	0.58	1.31	45.6	0.10	0.55	0.06	0.03	0.03	35	39.8	98.2
51	616.60	3.28	0.31	0.19	1.09	52.1	0.12	0.13	0.01	0.02	0.03	48	41.7	99.0
52	617.62	1.00	0.34	0.34	0.78	54.2	0.16	0.12	0.00	0.02	0.02	69	42.0	99.0
53	621.23	2.89	0.43	0.27	1.05	52.2	0.13	0.17	0.01	0.00	0.05	50	41.9	99.1

NOTE: D = Duplicate Analysis

Where SiO_2 and Al_2O_3 values are over range, the 'total' column is less than 100%

TABLE 4 Cont'd.: Chemical Analysis by XRF for Milton Borehole

PICKERING BOREHOLE														
M.T.C. SAMPLE NO.	M.N.R. SAMPLE NO. (meters)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	CaO: MgO	L.O.I.	TOTAL
54	51.90	18.7	4.15	1.24	2.55	34.2	0.12	0.94	0.17	0.06	0.05	13	34.2	96.4
55	53.02	6.65	1.35	0.53	0.95	49.1	0.10	0.38	0.05	0.04	0.04	52	40.2	99.4
56	53.74	6.34	1.46	0.47	0.88	49.6	0.13	0.38	0.05	0.04	0.04	56	40.2	99.6
57	54.76	12.7	3.05	0.76	1.47	40.9	0.11	0.73	0.12	0.08	0.04	28	37.1	97.1
58	60.11	9.21	2.21	0.59	1.24	45.3	0.11	0.58	0.08	0.04	0.04	36	39.2	98.6
59	62.41	11.7	2.72	0.70	1.57	42.2	0.11	0.72	0.10	0.04	0.04	27	38.1	98.0
60	64.07	11.1	2.40	0.67	1.49	43.3	0.10	0.63	0.08	0.04	0.04	29	38.6	98.5
61	64.87	16.6	3.63	0.91	1.86	37.0	0.10	0.87	0.14	0.04	0.04	20	35.7	96.9
62	66.00	5.53	1.34	0.52	1.40	50.2	0.14	0.35	0.04	0.03	0.03	36	41.0	100.5
63	67.00	9.80	2.20	0.61	1.24	45.0	0.08	0.59	0.08	0.04	0.03	36	37.6	97.3
64	68.10	8.75	1.93	0.54	1.21	46.1	0.12	0.54	0.07	0.04	0.03	38	39.5	98.8
65	69.00	13.4	2.97	0.74	1.58	40.5	0.10	0.76	0.11	0.04	0.03	26	37.6	97.8
65D		13.5	3.03	0.75	1.57	40.4	0.20	0.76	0.11	0.04	0.03	26	37.2	97.6
66	69.98	10.1	2.26	0.66	1.40	44.1	0.11	0.62	0.08	0.04	0.03	31	38.9	98.3
67	71.58	20.7	4.25	1.03	2.19	33.5	0.07	1.05	0.16	0.04	0.04	15	34.2	97.2
68	71.76	23.2	4.91	1.13	2.24	31.5	0.14	1.11	0.19	0.04	0.03	14	33.1	97.6
69	73.44	5.86	1.24	0.49	0.94	50.4	0.13	0.36	0.04	0.04	0.03	54	40.4	99.9
70	74.50	25.6	5.19	1.12	2.41	30.9	0.10	1.18	0.19	0.03	0.03	13	32.7	99.5
71	75.66	19.7	4.00	1.02	2.39	34.5	0.12	0.98	0.14	0.04	0.03	14	34.8	97.7
72	76.81	14.8	3.04	0.80	1.74	39.2	0.11	0.80	0.11	0.04	0.03	22	36.6	97.0
73	77.73	5.76	1.24	0.65	1.66	48.9	0.25	0.32	0.03	0.04	0.03	29	40.8	99.7
74	78.05	20.2	4.29	1.00	2.13	34.4	0.24	1.00	0.15	0.05	0.03	16	34.1	97.0
75	79.11	4.79	0.97	0.60	1.42	49.9	0.21	0.29	0.03	0.03	0.03	35	40.6	98.2
76	197.14	3.20	0.55	0.25	0.64	52.6	0.22	0.17	0.01	0.00	0.04	82	41.9	99.6
77	198.04	3.31	0.85	0.29	0.76	52.0	0.24	0.26	0.02	0.01	0.03	68	41.5	99.3
78	199.08	1.25	0.35	0.19	0.53	53.8	0.28	0.12	0.01	0.01	0.04	101	43.1	99.7
79	200.00	2.18	0.71	0.26	0.69	52.8	0.24	0.22	0.02	0.01	0.04	76	42.3	99.5
80	201.05	1.10	0.38	0.21	0.56	53.9	0.27	0.12	0.01	0.01	0.04	96	42.4	99.0
81	202.84	1.33	0.25	0.18	0.53	54.2	0.28	0.08	0.00	0.01	0.04	102	42.6	99.5
82	203.99	1.51	0.31	0.19	0.55	54.0	0.27	0.12	0.01	0.01	0.05	98	42.3	99.3
83	207.81	1.04	0.26	0.18	0.53	54.5	0.23	0.11	0.01	0.01	0.07	103	42.5	99.4
84	209.93	4.02	1.12	0.32	1.02	51.4	0.22	0.47	0.03	0.00	0.06	50	41.0	99.7

NOTE: D = Duplicate Analysis

Where SiO_2 and Al_2O_3 values are over range, the 'total' column is less than 100%

TABLE 5: Chemical Analysis by XRF for Pickering Borehole

PICKERING BOREHOLE														
M.T.C. SAMPLE NO.	M.N.R. SAMPLE NO. (meters)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	CaO: MgO	L.O.I.	TOTAL
85	211.95	4.12	1.14	0.89	13.7	35.3	0.07	0.41	0.05	0.00	0.23	2.6	42.7	98.6
85D		4.13	1.15	0.89	13.7	35.3	0.09	0.41	0.05	0.00	0.23	2.6	42.8	98.8
86	213.16	28.1	6.75	1.87	11.5	20.6	0.11	1.87	0.28	0.01	0.11	1.8	30.2	101.4
87	214.00	7.94	2.00	0.92	4.94	40.0	0.18	0.79	0.07	0.00	0.15	8.1	38.4	95.4
88	214.95	3.78	1.04	0.42	1.54	51.0	0.24	0.44	0.03	0.01	0.10	33	41.1	99.7
89	216.11	2.27	0.55	0.31	1.81	51.9	0.23	0.26	0.02	0.01	0.10	29	42.2	99.7
90	217.01	1.49	0.28	0.35	2.98	51.2	0.24	0.11	0.01	0.01	0.15	17	43.0	99.7
91	217.97	0.83	0.11	0.22	1.16	53.2	0.27	0.05	0.00	0.01	0.11	46	42.9	98.9
92	218.88	1.52	0.42	0.37	7.63	45.3	0.15	0.14	0.01	0.01	0.12	5.9	43.8	99.5
93	220.00	5.90	1.35	0.57	1.74	47.2	0.24	0.55	0.06	0.00	0.10	27	1.9	59.6
94	221.06	1.91	0.38	0.42	3.50	50.5	0.20	0.16	0.01	0.01	0.19	14	42.7	100.0
95	221.83	2.28	0.60	0.29	1.01	52.5	0.39	0.25	0.01	0.01	0.10	52	42.1	99.5
96	223.96	6.26	1.48	0.45	1.68	46.6	0.20	0.71	0.05	0.00	0.11	28	39.6	97.1
97	224.95	26.8	5.56	1.65	13.5	20.7	0.12	1.46	0.30	0.07	0.13	1.5	29.4	99.7

NOTE: D = Duplicate Analysis

Where SiO_2 and Al_2O_3 values are over range, the 'total' column is less than 100%

TABLE 5 Cont'd.: Chemical Analysis by XRF for Pickering Borehole

CLARKSON BOREHOLE														
M.T.C. SAMPLE NO.	M.N.R. SAMPLE NO. (meters)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	CaO: MgO	L.O.I.	TOTAL
98	438.95	1.34	0.35	0.23	0.76	54.0	0.26	0.12	0.01	0.01	0.03	71	42.7	99.8
99	439.41	0.97	0.20	0.15	0.53	54.3	0.29	0.06	0.00	0.01	0.02	102	42.0	98.5
100	440.37	0.06	0.13	0.15	0.34	55.6	0.27	0.04	0.00	0.01	0.03	163	43.1	99.7
101	441.23	1.52	0.33	0.26	2.94	51.9	0.21	0.13	0.01	0.01	0.05	18	42.7	100.1
102	442.40	0.86	0.37	0.18	0.57	54.5	0.23	0.14	0.01	0.01	0.04	96	42.6	99.5
103	443.35	1.11	0.25	0.18	0.59	54.5	0.27	0.09	0.00	0.01	0.04	92	42.7	99.7
104	444.11	4.75	1.11	0.35	0.98	50.9	0.25	0.38	0.04	0.01	0.03	52	40.4	99.2
105	444.96	1.64	0.40	0.24	1.51	53.0	0.23	0.16	0.01	0.00	0.06	35	42.5	99.8
105D		1.63	0.41	0.24	1.48	53.0	0.23	0.16	0.01	0.01	0.06	36	42.4	99.6
106	446.66	4.51	1.39	0.35	1.38	50.5	0.23	0.52	0.05	0.00	0.03	36	41.3	100.2
107	447.70	10.3	2.90	1.03	13.1	29.8	0.10	0.95	0.12	0.00	0.06	2.3	39.6	98.0
108	448.53	2.19	0.46	0.44	5.58	48.8	0.21	0.18	0.02	0.01	0.09	8.7	42.8	100.7
109	449.46	1.75	0.56	0.18	0.70	53.7	0.25	0.21	0.01	0.01	0.04	77	42.8	100.2
110	450.42	2.73	0.71	0.24	1.35	52.3	0.23	0.29	0.02	0.01	0.05	39	42.0	99.9
111	451.45	1.37	0.39	0.18	0.82	53.9	0.25	0.16	0.01	0.01	0.05	66	42.7	99.8
112	452.43	5.22	1.44	0.61	7.61	40.6	0.17	0.50	0.05	0.01	0.06	5.3	41.2	97.5
113	454.13	0.28	0.06	0.12	0.23	55.4	0.27	0.02	0.00	0.01	0.03	241	43.3	99.7
114	454.91	2.33	0.58	0.31	3.53	50.0	0.21	0.22	0.01	0.01	0.05	14	42.8	100.0
115	455.98	1.46	0.46	0.26	2.35	51.8	0.22	0.17	0.01	0.01	0.04	22	43.1	99.9
116	457.00	2.12	0.19	0.23	3.20	50.9	0.23	0.07	0.00	0.01	0.06	16	43.3	100.3
117	465.65	0.99	0.16	0.25	2.94	51.7	0.23	0.05	0.00	0.01	0.06	17	43.6	100.0
118	466.60	3.81	0.15	0.23	2.39	50.9	0.23	0.05	0.00	0.01	0.06	21	42.2	100.0
119	467.55	0.74	0.11	0.37	4.75	49.8	0.20	0.04	0.00	0.01	0.10	10	44.1	100.2
120	468.60	0.97	0.19	0.26	2.87	51.8	0.22	0.07	0.00	0.01	0.07	18	43.0	99.5
121	469.53	1.76	0.47	0.29	0.86	53.6	0.27	0.16	0.01	0.01	0.02	62	41.7	99.2
122	470.55	2.88	0.66	0.25	0.76	52.8	0.23	0.25	0.01	0.01	0.03	69	41.7	99.6
123	472.82	4.50	1.15	0.55	9.24	39.2	0.11	0.46	0.04	0.00	0.08	4.2	42.5	97.8
124	474.00	1.54	0.29	0.28	2.07	48.2	0.28	0.11	0.01	0.00	0.07	23	39.4	92.3

NOTE: D = Duplicate Analysis

Where SiO_2 and Al_2O_3 values are over range, the 'total' column is less than 100%

TABLE 6: Chemical Analysis by XRF for Clarkson Borehole

MILTON BOREHOLE

M.T.C. SAMPLE NO.	M.N.R. SAMPLE NUMBER (meters)	CORE ORIENTATION	INSOLUBLE RESIDUE (%)	ROCK CYLINDER EXPANSION, PERCENT 1 Wk.	2 Wks.	3 Wks.	4 Wks.	6 Wks.	12 Wks.	16 Wks.	28 Wks.	52 Wks.
1	218.39	Vert.	3.5	-.007	0.007	-.007	-.014	-.007		-.007	-.014	-.014
2	219.37	Horz.	19.1	0.038	0.023	0.015	0.015	0.023		0.023	0.038	0.046
3	442.30	Horz.	20.9	0.024	0.056	0.120	0.160	0.224		0.504	0.680	0.752
4	445.95	Horz.	8.5	0.000	0.000	0.000	0.000	0.000		-.007	-.007	-.007
5	446.85	Horz.	7.3	0.000	0.020	0.013	0.013	0.020		0.033	0.046	0.052
6	448.20	Vert.	15.6	0.025	0.049	0.074	0.090	0.107		0.180	0.262	0.312
7	449.20	Vert.	9.2	0.014	0.014	0.029	0.029	0.036		0.058	0.094	0.115
8	450.18	Vert.	7.2	0.015	0.030	0.044	0.044	0.059		0.119	0.163	0.185
9	451.08	Vert.	10.0	0.026	0.059	0.092	0.118	0.151		0.275	0.373	0.465
10	452.04	Vert.	9.4	0.021	0.042	0.076	0.097	0.132		0.250	0.320	0.389
11	452.77	Vert.	8.0	0.013	0.033	0.053	0.066	0.099		0.185	0.251	0.297
12	454.66	Vert.	11.9	0.052	0.096	0.140	0.170	0.229		0.406	0.532	0.665
13	455.80	Vert.	10.4	0.056	0.121	0.185	0.225	0.298		0.539	0.700	0.853
14	461.52	Horz.	7.5	-.008	-.008	0.000	0.000	0.017		0.034	0.051	0.042
15	462.53	Vert.	13.3	0.050	0.083	0.140	0.182	0.231		0.446	0.545	0.627
16	464.40	Horz.	9.5	0.025	0.041	0.074	0.099	0.132		0.222	0.264	0.313
17	465.55	Horz.	13.0	0.014	0.048	0.076	0.090	0.110		0.186	0.255	0.331
18	466.54	Horz.	23.5	0.084	0.145	0.183	0.213	0.244		0.343	0.396	0.427
19	467.72	NC.	-	-	-	-	-	-		-	-	-
20	468.20	Vert.	16.5	0.101	0.194	0.295	0.328	0.489		0.792	0.947	1.072
21	469.10	Vert.	5.1	-.007	0.000	0.000	-.007	0.000		0.156	C.B.	-
22	470.20	Vert.	21.7	0.078	0.125	0.187	0.211	0.218		0.312	0.343	0.367
23	471.22	Vert.	2.1	0.007	0.021	0.021	0.014	0.021		0.021	0.021	0.028
24	472.32	NC.	-	-	-	-	-	-		-	-	-
25	473.31	Vert.	25.0	0.220	0.343	0.481	0.556	0.639		0.948	1.127	1.312
26	474.22	Horz.	13.3	0.091	0.140	0.182	0.210	0.252		0.427	0.616	1.079
27	475.60	Vert.	14.7	0.014	0.028	0.042	0.056	0.070		0.126	0.147	0.196
28	476.77	Vert.	13.7	0.201	0.454	CB.	CB.	-		-	-	-
29	477.73	Vert.	18.9	0.150	0.240	0.330	CB.	-		-	-	-
30	479.68	Horz.	13.7	0.075	0.128	0.135	0.143	0.150		0.218	0.263	0.308
31	480.66	Vert.	4.4	-.007	-.007	-.007	-.014	-.014		-.014	-.014	-.036
32	481.21	Diag.	19.3	0.016	0.008	0.031	0.039	0.039		0.063	0.086	0.094
33	482.08	Vert.	8.3	0.008	0.024	0.040	0.055	0.071		0.095	0.134	0.158
34	596.13	Vert.	1.2	-.009	-.009	-.009	-.009	-.017		-.026	-.017	-.026
35	597.75	Vert.	2.0	-.007	-.007	-.007	-.007	-.007		-.014	-.014	-.021
36	597.34	Horz.	7.3	0.000	0.060	-.007	-.007	-.013		-.020	-.013	-.020
37	598.42	Vert.	1.2	-.014	-.028	-.028	-.028	-.042		-.042	-.042	-.049
38	599.15	Vert.	1.3	-.007	-.007	-.014	-.007	-.014		-.021	-.021	-.029
39	600.06	Vert.	1.2	-.007	-.014	-.014	-.007	-.014		-.028	-.028	-.042
40	601.27	Horz.	2.3	0.000	0.000	-.007	-.007	-.007		-.014	-.014	-.021
41	602.24	Vert.	2.3	-.008	-.015	-.008	-.008	-.015		-.023	-.008	-.008
42	602.81	Vert.	4.9	0.000	0.007	0.022	0.030	0.052		0.119	0.164	0.216
43	603.74	Vert.	2.8	0.000	0.000	0.000	0.007	0.000		0.007	0.015	0.015
44	604.82	Vert.	5.5	0.008	0.015	0.023	0.030	0.030		0.045	0.053	0.053
45	606.08	Vert.	11.9	0.008	0.000	0.008	0.008	0.008		0.008	0.038	0.045
46	606.61	Vert.	3.3	0.007	0.021	0.021	0.028	0.035		0.049	0.077	0.097
47	607.38	Vert.	4.6	0.007	0.014	0.020	0.027	0.027		0.041	0.061	0.074
48	610.13	Vert.	3.1	0.000	0.000	0.000	0.000	0.000		0.000	0.007	0.007
49	613.96	Vert.	2.8	0.055	0.075	0.089	0.102	0.109		0.143	0.171	0.184
50	615.28	Horz.	10.5	0.000	0.000	0.015	0.015	0.023		0.045	0.060	0.075
51	616.60	Vert.	5.3	0.000	-.006	-.006	0.000	-.006		-.006	-.006	-.006
52	617.62	Vert.	2.7	-.014	-.014	-.021	-.021	-.021		-.029	-.029	-.036
53	621.23	Vert.	3.7	-.007	-.017	-.007	-.007	-.007		-.015	-.007	-.015

NOTE: CB. = Cylinder broke due to excessive expansion
NC. = No core available
Vert. = Cylinder cut perpendicular to bedding
Horz. = Cylinder cut horizontal to bedding
Diag. = Cylinder cut diagonally

TABLE 7: Results of Insoluble Residue Test and Rock Cylinder Expansion Test (ASTM C586) for Milton Borehole Samples

PICKERING BOREHOLE

M.T.C. SAMPLE NO.	M.N.R. SAMPLE NUMBER (meters)	CORE ORIENTATION	INSOLUBLE RESIDUE (%)	ROCK CYLINDER EXPANSION, PERCENT 1 Wk.	2 Wks.	3 Wks.	4 Wks.	6 Wks.	12 Wks.	16 Wks.	24 Wks.	52 Wks.
54	51.90	Vert.	22.8	0.147	0.241	0.342	0.442	0.583	0.971	1.320	1.420	
55	53.02	Vert.	8.0	-.007	-.007	-.014	-.014	-.014	-.029	-.021	-.029	
56	53.74	Vert.	11.3	0.007	0.000	0.000	0.007	0.007	0.021	0.035	0.042	
57	54.76	Vert.	15.7	-.007	-.007	-.007	0.000	0.000	0.007	0.014	0.014	
58	60.11	Vert.	7.9	0.014	0.028	0.028	0.043	0.050	0.092	0.135	0.163	
59	62.41	Vert.	13.6	0.149	0.356	0.306	0.422	0.537	1.290	C.B.	-	
60	64.07	Vert.	12.9	0.104	0.160	0.202	0.265	0.320	0.529	0.676	0.752	
61	64.87	Vert.	19.7	0.070	0.101	0.156	0.249	0.304	0.647	0.787	0.834	
62	66.00	Vert.	6.8	0.182	0.437	0.734	1.040	CB.	2.000	C.B.	-	
63	67.00	Horz.	11.8	0.064	0.060	0.121	0.171	0.214	0.406	0.534	0.591	
64	68.10	Vert.	10.6	0.071	0.134	0.191	0.304	0.452	0.761	C.B.	-	
65	69.00	Vert.	14.9	0.171	0.256	0.363	0.527	0.712	1.459	1.844	1.922	
66	69.98	Vert.	11.7	0.029	0.044	0.066	0.118	0.140	0.308	0.389	0.455	
67	71.58	Vert.	6.7	0.000	-.007	-.007	0.000	-.007	-.014	-.007	0.000	
68	71.76	Horz.	25.0	0.058	0.130	0.188	0.282	0.348	0.659	0.796	0.811	
69	73.44	Vert.	22.7	0.102	0.184	0.273	0.403	0.512	0.928	1.051	1.085	
70	74.50	Horz.	26.8	0.033	0.065	0.117	0.150	0.209	0.359	0.444	0.476	
71	75.66	Horz.	20.7	-.007	-.007	0.000	0.007	0.007	0.000	0.015	0.015	
72	76.81	Vert.	16.5	0.056	0.072	0.128	0.160	0.192	0.352	0.401	0.449	
73	77.73	Vert.	6.3	0.039	0.065	0.091	0.104	0.130	0.214	0.266	0.292	
74	78.05	Diag.	22.3	0.023	0.008	0.031	0.031	0.023	0.070	0.085	0.093	
75	79.11	Vert.	6.5	0.000	0.008	0.000	0.000	-.008	-.023	-.016	-.008	
76	197.14	Vert.	4.1	0.000	-.007	-.007	-.007	-.013	0.020	-.007	-.007	
77	198.04	Vert.	4.6	0.006	-.006	0.000	0.000	-.006	-.006	0.000	0.000	
78	199.08	Horz.	2.2	0.007	0.000	0.000	0.000	0.007	-.007	-.007	-.022	
79	200.00	Vert.	3.1	0.000	0.000	-.007	0.000	0.000	-.014	-.007	-.014	
80	201.05	Vert.	2.3	0.000	0.000	0.000	-.007	-.007	-.013	-.007	-.013	
81	202.84	Horz.	2.4	0.000	0.000	-.007	0.000	-.007	-.007	-.007	-.007	
82	203.99	Vert.	2.5	-.007	-.007	-.014	-.014	-.014	-.014	-.014	-.020	
83	207.81	Vert.	1.6	-.007	-.007	-.007	0.000	-.007	-.014	-.014	-.014	
84	209.93	Vert.	5.5	0.000	0.000	0.000	0.000	0.000	-.008	0.008	0.000	
85	211.95	Vert.	5.3	0.000	0.007	0.007	0.007	0.013	0.027	0.053	0.067	
86	213.16	Horz.	31.9	0.015	-.029	0.015	0.000	0.015	0.029	0.044	0.052	
87	214.00	Vert.	12.0	0.080	0.160	0.240	0.298	0.364	0.539	0.662	CB.	
88	214.95	Vert.	5.8	0.013	0.007	0.033	0.040	0.053	0.112	0.198	0.271	
89	216.11	Vert.	3.2	0.000	0.000	0.000	0.000	0.000	-.007	0.014	0.014	
90	217.01	Vert.	1.8	0.007	0.007	0.007	0.007	0.007	0.007	0.014	0.022	
91	217.97	Vert.	1.1	-.015	-.007	-.015	-.015	-.015	-.015	-.015	-.015	
92	218.88	Vert.	1.9	0.013	0.027	0.046	0.046	0.060	0.080	0.106	0.146	
93	220.00	Vert.	9.4	0.000	-.013	0.000	0.000	0.000	0.000	0.007	0.007	
94	221.06	Vert.	2.9	0.000	0.007	0.007	0.007	0.014	0.014	0.021	0.041	
95	221.83	Vert.	3.5	-.040	-.040	-.040	-.047	-.040	-.054	-.047	-.040	
96	223.96	Vert.	8.4	0.007	0.000	0.080	0.015	0.015	0.029	0.073	0.131	
97	224.95	Vert.	32.7	0.020	0.020	0.040	0.034	0.027	0.054	0.081	0.081	

NOTE: Vert. = Cylinder cut perpindicular to bedding
Horz. = Cylinder cut horizontal to bedding
Diag. = Cylinder cut diagonally

TABLE 8: Results of Insoluble Residue Test and Rock Cylinder Expansion Test (ASTM C586) for Pickering Borehole Samples

CLARKSON BOREHOLE

M.T.C. SAMPLE NO.	M.N.R. SAMPLE NUMBER (meters)	CORE ORIENTATION	INSOLUBLE RESIDUE (%)	ROCK CYLINDER EXPANSION, PERCENT 1 Wk.	2 Wks.	3 Wks.	4 Wks.	6 Wks.	12 Wks	16 Wks.	28 Wks.	52 Wks.
98	438.95	Horz.	1.9	0.000	0.000	-.006	-.013	-.006		-.026	-.019	-.026
99	439.41	Horz.	2.7	0.000	-.007	-.007	-.007	0.013		-.013	0.013	-.013
100	440.37	Horz.	0.3	0.000	0.000	0.000	-.008	-.008		-.025	-.008	-.025
101	441.23	Vert.	2.1	-.008	-.008	-.008	-.008	-.008		-.016	-.008	-.008
102	442.40	Horz.	1.3	0.000	0.000	0.000	0.000	-.007		-.022	-.015	-.029
103	443.35	Horz.	1.2	0.000	0.000	0.000	0.000	0.007		-.007	-.007	-.007
104	444.11	Diag.	5.7	0.000	0.006	0.000	0.006	0.013		0.000	0.006	0.000
105	444.96	Vert.	2.4	0.000	0.008	0.008	0.008	0.008		0.008	0.023	0.038
106	446.66	Horz.	5.9	0.007	0.014	0.022	0.029	0.043		0.072	0.108	0.122
107	447.70	Vert.	12.6	0.014	0.022	0.022	0.029	0.029		0.036	0.065	0.086
108	448.53	Vert.	3.7	-.007	0.000	0.000	0.000	0.000		0.000	0.014	0.021
109	449.46	Vert.	2.6	0.000	0.000	0.000	0.000	-.007		-.007	-.007	-.007
110	450.42	Horz.	3.8	-.008	0.000	0.000	0.000	0.000		0.000	0.008	0.015
111	451.45	Vert.	2.1	-.014	-.021	-.021	-.021	-.014		-.028	-.014	-.014
112	452.43	Horz.	6.9	0.175	0.547	0.817	0.883	0.926		1.014	1.080	1.109
113	454.13	Vert.	0.7	0.000	-.007	-.007	-.015	-.015		-.030	-.030	-.037
114	454.91	Vert.	3.0	-.022	0.067	0.075	0.082	0.082		0.105	0.135	0.165
115	455.98	Vert.	2.3	0.000	0.007	0.007	0.014	0.021		0.028	0.042	0.055
116	457.00	Vert.	2.6	0.008	0.008	0.008	0.015	0.023		0.015	0.038	0.107
117	465.65	Vert.	1.5	0.000	0.000	-.007	-.007	-.007		-.014	-.007	0.000
118	466.60	Vert.	4.3	-.007	0.000	-.007	-.007	-.007		-.007	0.000	0.000
119	467.55	Horz.	1.2	-.007	-.007	-.007	-.007	-.007		-.014	-.007	0.000
120	468.60	Vert.	1.5	0.000	0.000	0.000	0.007	0.000		0.007	0.007	0.034
121	469.53	Vert.	3.0	0.000	0.000	0.000	0.000	0.007		-.007	0.007	0.007
122	470.55	Vert.	4.2	0.000	-.007	-.007	-.007	-.007		-.014	-.007	-.007
123	472.82	Vert.	5.8	0.000	0.000	0.007	0.014	0.091		0.183	0.239	0.358
124	474.00	Vert.	2.3	0.000	0.007	0.000	0.000	0.000		-.007	0.007	0.020
125	477.18	NC.	-	-	-	-	-	-		-	-	-

NOTE: NC. = No core available
Vert. = Cylinder cut perpendicular to bedding
Horz. = Cylinder cut horizontal to bedding
Diag. = Cylinder cut diagonally

TABLE 9: Results of Insoluble Residue Test and Rock Cylinder Expansion Test (ASTM C586) for Clarkson Borehole Samples

	LINDSAY FORMATION		VERULAM FORMATION		BOBCAYGEON FORMATION		GULL RIVER FORMATION	
	TOTAL	WATER SOL.	TOTAL	WATER SOL.	TOTAL	WATER SOL.	TOTAL	WATER SOL.
MILTON BOREHOLE	.0045 .0413 .0244 .0448	.0018 .0389 .0214 .0426	.0472	.0460			.0248 .0569 .1760 .0541 .0567	.0211 .0514 .1668 .0462 .0484
	Avge. .0288	Avge. .0262	Avge. .0472	Avge. .0460	--	--	Avge. .0737	Avge. .0668
PICKERING BOREHOLE	.0678 .0637 .0694 .0658	.0630 .0603 .0644 .0633	.0701	.0690	.0434	.0433	.0346 .0110 .0374	.0301 .0064 .0291
	Avge. .0667	Avge. .0628	Avge. .0701	Avge. .0690	Avge. .0434	Avge. .0433	Avge. .0277	Avge. .0219
CLARKSON BOREHOLE	--	--	--	--	--	--	.0457 .0852 .0813 Avge. .0707	.0420 .0766 .0706 Avge. .0630
AVERAGE FOR GEOLOGICAL FORMATION	.0478	.0445	.0587	.0575	.0434	.0433	.0603	.0535

TABLE 10: Total and Water Soluble Chloride Ion Content in Percent

Appendix 1

Ministry of Transportation and Communications

Quality Requirements for Coarse Aggregates

TYPE OF MATERIAL \ TYPE OF TEST		PETROGRAPHIC NUMBER MAXIMUM	$Mg\ SO_4$ MAXIMUM % LOSS	ABSORPTION MAXIMUM %	LOS ANGELES MAXIMUM % LOSS
GRANULAR BASE	A	200			60
16 mm CR. TYPE "B"		200			60
GRANULAR SUBBASE	B	250			
	C	250			
	D				
HOT MIX - H.L.	3	135	12	1.75	35
	4	160	12	2.0	35
	8	160	15	1.75	35
SURFACE TREATMENT					
CLASS 3		135	12	1.75	35
CLASS 2		160			35
STRUCTURAL CONCRETE AND CONCRETE BASE		140	12	2.0	35
CONCRETE PAVEMENT		125	12	2.0	35